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PERMO-CARBONIFEROUS CLIMATIC CHANGES IN SOUTH AMERICA

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INTRODUCTION

The presence in Argentina and Brazil of representatives of the Lower Gondwana, or *Gangamopteris* flora has for some years been definitely recognized through the small collections examined by Professors Zeiller[1] and Kurtz.[2] More recently, however, the Coal Commission of Brazil has placed in the writer's hands a number of fossil plant collections which, though lacking much both in quantity and preservation, are definitely fixed stratigraphically, while embracing a considerable vertical range.

The new material, from the coalfields, chiefly of the states of Santa Catharina and Rio Grande do Sul, in Brazil, not only confirms the presence in that country of the Lower Gondwana flora, but it also throws new light on the geographical relations and climatic changes in this quarter of the earth during Permo-Carboniferous time. The purpose of this paper is particularly to call attention to some of the physical conditions indicated with more or less distinctness by the fossil floras, and briefly to state the conclusions drawn or opinions entertained by the writer in an attempt to account for certain changes in climate.

[1] *Comptes Rendus*, Vol. CXXI, 1895, p. 961; *Bull. Soc. géol. Fr.* (3), Vol. XXIII, 1896, p. 601.

[2] *Rev. Mus. de la Plata*, Vol. VI, 1894, p. 125; *Bull. Soc. géol. Fr.* (3), Vol. XXIV, 1896, p. 466.

The stratigraphical series in the coal basins of the state of Santa Catharina as published by Dr. I. C. White, late chief of the commission, is essentially as follows:[1]

Santa Catharina System:

São Bento Series:	Serra Geral eruptives. Botucatú sandstones, great cliffs of red, gray, and cream-colored sandstones. Rio do Pasto red beds, with fossil reptiles (*Scaphonyx* and *Erythrosuchus*) and fossil trees.
Passa Dois Series:	Rocinha limestone. Estrada Nova gray and variegated shales with cherty concretions, and sandy beds. Iraty black shale, *Mesosaurus* and *Stereosternum*.
Tubarão Series:	Palermo shales. Rio Bonito shales and sandstones, with coal measures and Gangamopteris (Glossopteris) flora. Orleans conglomerate. [Glacial] Yellow sandstones and shales to granite floor.

SYNOPSIS OF THE PALEOBOTANICAL DATA

On the side of the fossil plants it will be possible to give in this place only an enumeration of the species, with references to their stratigraphical position in Brazil. For the descriptions and other taxonomic data relating to the species the reader is referred to the report of the commission. In the following list[2] the species characteristic of the Gondwana series in other continents are marked by an asterisk (*), those clearly representing Gondwana types but comprising forms previously unknown are designated by the double asterisk (**), those generally regarded as proper to the Permo-Carboniferous of the Northern Hemisphere by a dagger (†), while those of mixed distribution or of unascertained geographical significance are indicated by the double dagger (††).

Rosellinites Gangamopteridis D. W.**; Hysterites brasiliensis D. W.**; Equisetites calamitinoides D. W.††; Schizoneura ? sp.**; Phyllotheca Griesbachi

[1] *Science*, Vol. XXIV, No. 612, 1906, p. 377.

[2] *Reinshia australis* Bertr. & Ren. var. *brasiliensis*, which is included in the descriptive memoir, is here omitted, since from evidence kindly communicated by Dr. Derby it appears probable that the specimens in the Brazilian Exhibit at the St. Louis Exposition were first brought to Brazil from Australia.

Zeill.*; Phylotheca Muelleriana D. W.**; Phylotheca (?) sp.**; Lycopodiopsis Derbyi Ren.††; Lepidodendron Pedroanum (Carr.) Zeill.††; Lepidophloios laricinus Sternb.†; Sigillaria Brardii Brongn.†; Sigillaria austarlis D. W.††; Sigillaria sp.††; Sigillaria (?) muralis D. W.††; Sphenopteris hastata McCoy?*; Sphenopteris sp.**; Psaronius brasiliensis Brongn.**;[1] Neuropteridium Plantianum (Carr.) D. W.[1] (*N. validum*)*; Glossopteris Browniana Brongn.*; Glossopteris indica (Brongn.) Schimp.*; Glossopteris ampla Dana.*; Glossopteris occidentalis D. W.**; Glossopteris sp.**; Vertebraria sp.**; Gangamopteris obovata (Carr.) D. W.* (*G. cyclopteroides*); Ottokaria ovalis D. W.**; Arberia minasica D. W.**; Derbyella aurita D. W.**; Noeggerathiopsis Hislopi (Bunb.) Feist.*; Cardiocarpon Seixasi D. W.††; Cardiocarpon Moreiranum D. W.††; Cardiocarpon Oliveiranum D. W.††; Cardiocarpon Barcellosium D. W.††; Voltzia? sp.††; Dadoxylon Pedroi Zeill.††; Dadoxylon nummularium D. W.††; Dadoxylon meridionale D. W.††; Carpolithus? sp.††; Hastimima Whitei D. W.**

FLORAS AND THEIR CLIMATIC SIGNIFICANCE

The examination of the stratigraphical occurrence of the species just enumerated indicates that at the base of the Brazilian coal measures we have a Lower Gondwana flora essentially identical with that found in the corresponding beds in India, Australia, and South Africa; and that in the higher beds we have the introduction of Northern Permo-Carboniferous types which appear to indicate the progress of a great climatic change. The data bearing on this matter are briefly summarized in the following paragraphs:

Basal, Lower Gondwana Flora.—The only species collected from a shale lens but 6 meters above the unconformable crystalline floor of the coalfield is *Gangamopteris obovata* (*G. cyclopteroides*), one of the most characteristic as well as earliest of the Lower Gondwana plants.[2] The next higher plant bed of importance lies at a horizon but 55 meters above the granite floor near Minas, state of Santa Catharina, where we find, in the Minas formation, *Rosellinites Gangamopteridis, Hysterites brasiliensis, Phyllotheca Griesbachi, Phyllotheca Muelleriana, Phyllotheca* sp., *Glossopteris Browniana, Vertebraria* ?, *Gangamopteris obovata, Arberia minasica, Derbyella aurita,*

[1] Not represented in the collection.

[2] On account of its strictly Paleozoic distribution, wide geographical range, ready recognition, and pre-eminent characterization of the Lower Gondwana series GANGAMOPTERIS has been substituted by the writer for "*Glossopteris*," previously used to designate the flora, but which is unsuited therefor on account of its transgression in the Mesozoic and its nomenclatorial inapplicability.

Noeggerathiopsis Hislopi, Cardiocarpon (Samaropsis) Seixasi, Cardiocarpon Moreiranum, Voltzia ? sp., and *Hastimima Whitei.*

The flora enumerated above belongs to the early typical GANGAMOPTERIS or Lower Gondwana flora. The distribution of its identical or related species in other continents indicates contemporaneity with the Ecca shales of South Africa, the upper coal measures of New South Wales, the upper marine coal measures of Tasmania, and the Karharbari beds of India. Concomitantly the underlying Orleans conglomerate of the Brazilian region is correlated with the Dwyka conglomerates of South Africa, the Baccus Marsh conglomerates and their equivalents in Australia and Tasmania, and the Talchir conglomerates of India.

Cold climate of the basal flora.—The appearance of the GANGAMOPTERIS flora in its simple and relatively pure condition immediately above the basal bowlder beds of South America in a way exactly similar to its occurrence in India, Africa, and Australia bears irrefragable evidence of a corresponding similarity of the accompanying climate. The consequent inference that glacial conditions had preceded the flora in South America is verified by Dr. I. C. White's studies of the basal bowlder beds and conglomerates of the Santa Catharina series in which he finds distinctly glaciated material. The earlier suggestion by Dr. Orville A. Derby[1] that the basal Permo-Carboniferous bowlder beds of Brazil were associated with glacial activity in that continent thus finds a double confirmation.[2] As to the reality of glacial action during Permo-Carboniferous time it may be added that, notwithstanding the great differences of opinion as to causes, the work of ice, especially in South Africa where the glaciation was on a truly great scale, has been so convincingly demonstrated over large areas as no longer to be questioned or require the citation of further proof.[3]

[1] *Waagen, Rec. Geol. Surv. India,* Vol. XXII, Pt. 2, 1889, p. 69.

[2] In this connection it may be of interest to note that identical conclusions as to Paleozoic glaciation in Brazil were reached by Dr. White and the writer, one on purely geological evidence, the other on strictly paleobotanical data, each entirely without knowledge of the facts or opinions of the other.

[3] See T. W. E. David, *Quarterly Journal of the Geological Society of London,* Vol. LII, 1896, p. 289; Wm. M. Davis, *Bulletin of the Geological Society of America,* Vol. XVII, 1906, p. 47; Frech, *Lethaea Palaeozoica,* Vol. II, Lief. 4, 1902, p. 572; and Chamberlin and Salisbury, *Geology,* Vol. II, 1906, p. 538.

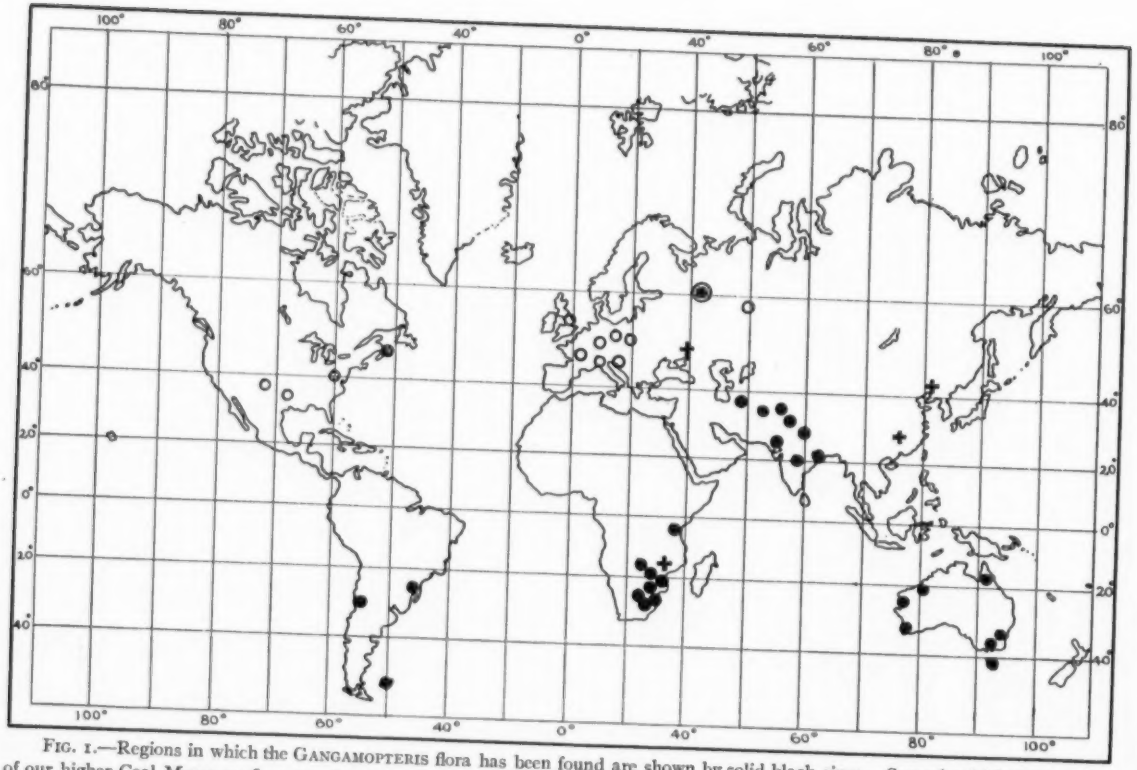

FIG. 1.—Regions in which the GANGAMOPTERIS flora has been found are shown by solid black rings. Several neighboring regions of our higher Coal Measures flora are shown by crosses. General regions of the Cosmopolitan Permian flora are indicated by white rings. The dark circle in the larger light ring designates mingling of Cosmopolitan and GANGAMOPTERIS types in the later Permian

The regional refrigeration which drove back or exterminated the Northern Permo-Carboniferous flora undoubtedly constituted the principal environmental cause in the development of the GANGAMOPTERIS flora. In the Greta series of New South Wales this flora appears to have been interglacial. The absence of cosmopolitan northern types, particularly of the Lycopods, from the beds immediately following the glacial conglomerates in Brazil, as well as in other areas of the pure GANGAMOPTERIS flora can have been due only to the inhospitability of the environment to those types at this time.

Beginning of return of northern types.—Although subsequent collections may show a lower range for some of the types, it would appear from the data at present available that in the Brazilian basins the first traces of Northern Permo-Carboniferous elements are met at 120 meters above the granite where we find Lepidophytic megaspores. At 135 meters above the granite—i. e., in the Nova Estrada formation—the same form of spores is mingled with cortical fragments and leaves of *Sigillaria*. With them are *Equisetites calamitinoides*, *Schizoneura* (?) sp., *Sigillaria australis*, *Sphenopteris hastata* (?), *Glossopteris indica*, *Glossopteris ampla*, *Glossopteris occidentalis*, *Noeggerathiopsis Hislopi*, and *Cardiocarpon Oliveiranum*. The flora as a whole is still overwhelmingly Southern, most of the species being characteristic of the older Gondwana series.

Continued climatic amelioration.—From a group of coals situated about 157 meters above the granite floor, and about 100 meters below the top of the Iraty black shale, which forms the base of the Passa Dois series, were collected *Lepidophloios laricinus*, *Glossopteris Browniana*, *Glossopteris indica*, *Glossopteris* sp., *Vertebraria* (?) sp., *Gangamopteris obovata*, *Noeggerathiopsis Hislopi*, *Cardiocarpon Moreiranum* and *Cardiocarpon Barcellosi*, while a carbonaceous stratum a little higher is largely composed of the remains of *Lepidodendron Pedroanum*, *Lepidophloios laricinus* and *Sigillaria Brardii*. The collections from these horizons are quite small and insufficient in species; but they are ample enough to show conclusively the presence of Lepidophytic elements typical of the Northern Permo-Carboniferous flora mingling with the GANGAMOPTERIS flora. It is interesting to note that at the level of the last-mentioned coal the Lycopods again establish their pre-eminent part as great coal-makers.

The climatic cycle.—So far as is known the floras preceding the period of Permo-carboniferous glaciation in India, Australia, South Africa, and South America were essentially identical with those of the northern hemisphere. The phytiferous strata as yet brought to light show the presence of the cosmopolitan or northern Lower Carboniferous flora in Argentina and Australia, of a Middle Coal Measures flora in the Heraclea basin in Asia Minor, and of a Stephanian flora (probably Upper Conemaugh or Monongahela in age), in the vicinity of Tete, on the Zambesi, in what was later the territory of the GANGAMOPTERIS flora in South Africa. The extermination of the northern, or cosmopolitan flora from the regions of the pure GANGAMOPTERIS flora can have been due only to the causes producing the glacial refrigeration and the GANGAMOPTERIS flora itself in those portions of the earth. The presence of a Sigillaria in the Ecca beds of South Africa, and the invasion by the above-named Lepidophytes in Brazil shows at once not only an amelioration of the climate sufficient for the return of some of the northern elements, but also that the extent of the land areas was such as to make their return possible. In fact, it is probable that no oceanic barrier existed to prevent free access of the northern types at any time during the period of cold. It is important to note that these hardy invaders from the northern flora which, under the influence of ameliorating climatic conditions were the first able to regain a foothold in the lost territory, belonged to the Lepidophytes, or Lycopodineous group.

It thus appears that in South America, as in South Africa, the Lepidophytes were the first to mingle with the flora which succeeded the glacial climate, the invaders being apparently in greater force in South America.[1] The greater variety as well as the far greater numerical representation of the Northern Lycopod elements in the Brazilian area may be due either to relative nearness to the border of

[1] Bodenbender reports the presence of *Lepidophloios laricinus, Sigillaria Brardii, Pachypteris,* and *Walchia* in Argentina. As to *Cardiopteris polymorpha, Adiantites antiquus,* and *Rachopteris* (Lower Carboniferous types), and *Lepidodendron selaginoides, L. aculeatum,* and *L. Veltheimianum* (Lower coal measures species) also reported by him there is room for doubt concerning either the identity of the plants or their relations to the GANGAMOPTERIS flora. See *Bot. Acad. Nac. Ciencias, Cordoba,* Vol. XVII, 1902, p. 203.

the refrigerated area, or to a more rapid and well-marked moderation of the climate.

Evidence of equable climate during Passa Dois deposition.—The fossil-plant material collected from higher horizons of the Brazilian coal measures unfortunately consists only of fossil stems; but these furnish almost unmistakable evidence of a mild and equable climate. From beds near the top of the Tubarão series, in Rio Grande do Sul, not far above the horizon last mentioned a gymnospermous type, *Dadoxylon* (?) *meridionale*, was collected. Another horizon somewhat higher, or about 75 meters above the base of the Passa Dois series, in the same state, furnished *Dadoxylon* (?) *nummularium* and a tree Lycopod of large size, *Sigillaria* (?) *muralis*. Still another fossil Lepidophyte, *Lycopodiopsis Derbyi*, was found at 155 meters above the Iraty black shale in the state of São Paulo. The Iraty black shale, which has been definitely traced by Dr. White throughout the region, is probably the source of the *Dadoxylon* (?) *Pedroi* Zeill., and of Brongniart's *Psaronius brasiliensis*. It is also the horizon of Cope's *Stereosternum tumidum* as well as of the *Mesosaurus brasiliensis* McGregor, collected by Dr. White.

Even more importantly significant than the presence of the arborescent Lycopods, from the climatic standpoint, is the complete or almost total absence from the various fossil woods of all trace of annual rings. On the other hand annual rings are conspicuously developed in the trees described by Arber[1] and Shirley[2] and found associated with the pure GANGAMOPTERIS flora in beds overlying the glacial conglomerates in New South Wales and Queensland. The sensible abatement of climatic rigor indicated by the appearance of the Lycopods in the upper part of the Tubarão series in Brazil is thus confirmed by the uninterrupted growth in the fossil trees from the still higher beds, during whose deposition there appear to have been no marked seasonal changes of climate. The presence of the large Lycopods and of the Psaronius trunk in the Passa Dois series warrants the expectation that further search will reveal a pteridophytic and gymnospermous flora closely related to the contemporaneous

[1] *Catalogue of the Fossil Plants of the Glossopteris Flora in the Department of Geology, British Museum*, 1905, p. 191.

[2] *Geol. Surv., Queensland*, Bull. No. 7, 1898, p. 14.

Northern Permian flora[1] and perhaps grown under climatic conditions but little dissimilar to those prevailing to the northward.

The large tree Lycopods and the Psaronius are sufficient evidence of the Paleozoic age of the environing rocks, and, therefore, of the greater part of the Passa Dois series. Likewise the occurrence of *Lycopodiopsis Derbyi* at the much higher horizon furnishes good ground for anticipating that the upper part also of the series will fall within the Permian limits. But the presence in the Rio do Pasto beds of Erythrosuchus and of *Scaphonyx Fischeri*, regarded as closely related to Euskelesaurus, of the Stormberg beds in South Africa, argues for the Triassic age of the red beds and eruptives of the succeeding São Bento series.

SUMMARY OF THE CLIMATIC CHANGES

Briefly summarized, the paleobotanical evidence now in hand, though very incomplete, goes to show:

1. The occurrence of the cosmopolitan or world-wide floras in various parts of the southern land areas up to a point somewhere in the Upper Coal Measures or upper Stephanian; and, consequently, a corresponding uniformity or equability of climate in both the northern and southern regions.

2. The presence, at the base of the Brazilian coal measures, of a pure GANGAMOPTERIS flora essentially identical with that found in beds following the glacial deposits of India, Australia, and South Africa, and undoubtedly existent under approximately identical climatic conditions.

3. Some moderation of the climate at an early date so as to permit the immigration of a few of the hardier Lycopodineous types from the contemporaneous Northern or "cosmopolitan" Permo-Carboniferous flora.

4. The restoration of an equable Permian climate in southern South America permitting the invasion of other Northern pteridophytic types and the growth of gymnospermous trees without annual rings.[2]

[1] The Psaronius perhaps belongs to the Cladophleboid group of Pecopterids.

[2] The close of the Permian in the Brazilian basins appears to have been marked by deposition of variegated shales and cherts indicating oxidization and probable retreat of the sea, comparable to the geological phenomena of the time in other parts of the world.

The period from the deposition of the lowest coals overlying the glacial bowlder material to the return of the Lepidophytes is believed by the writer to have been not long.[1] It seems probable that the return of an equable climate was as early as the beginning of the Damuda Series of the Gondwana System, or as the early Zechstein (Upper Permian) of the northern system.

THE GANGAMOPTERIS PROVINCE

The GANGAMOPTERIS flora appears to have flourished in a state of relative purity in the Permo-Carboniferous coalfields of India; in Queensland, New South Wales, Victoria, and Tasmania, in the Australian region; in German and Portuguese East Africa, Portuguese South-East Africa, Rhodesia, Zululand, the Transvaal, the Orange River Colony, Natal and Cape Colony in South Africa; and in Argentina and southern Brazil in South America. It appears to be present, perhaps in a less pure condition, in Kashmir, Afghanistan, and Persia, while a number of its characteristic elements mingled with northern types are found in the Upper Permian (Zechstein) of northern Russia and in the Altai Mountains. The territory of the pure or typical GANGAMOPTERIS flora may be termed the GANGAMOPTERIS Province. It conforms for the most part to the geographical, though not the geological, limits of the "Glossopteris Province" as the latter was proposed and defined by Professor Zeiller.[2]

The GANGAMOPTERIS or "Gondwana-land" continent.—The GANGAMOPTERIS flora is predominantly a terrestrial flora of somewhat highly varied composition. Hence the occurrence of this flora in great uniformity, including an extraordinarily high degree of specific identity, and in relative purity, contemporaneously in India,

[1] In Australia the more rigorous climate seems to have prevailed longer, with greater deposition of coal measures and with recurrence of glaciation. The Brazilian records may pertain only to the later of the ice extensions, or, on the other hand, regional subsidence or other related causes may sooner have brought amelioration in this quarter of the globe.

[2] *Rev. gén. d. science*, 8e *année*, 1907, p. 5. The GANGAMOPTERIS province embraces the regional distribution of the original or typical flora, while at the same time concerning only beds of Paleozoic age, thus escaping the regions of Mesozoic migration and mingling of the genus *Glossopteris* and several of its early associates with the northern post-Paleozoic flora. The genus Gangamopteris appears not to have survived the Permian.

Australia, South Africa, and southern South America, leaves no recourse but to conclude that the land surfaces over which it extended were in such continuity, or intimate geographical relation, as freely to permit the migration of the flora, practically *in toto*, between all these quarters of the globe.

The regions in which remains of the GANGAMOPTERIS flora have already been brought to light, are roughly indicated on the accompanying map, Fig. 1. The disposition of these areas, chiefly in the Southern Hemisphere, and their geographical relations to the present Antarctica, point strongly to the inclusion of the latter as an important part of a great continent or aggregate of very closely proximate land masses freely traversed by the GANGAMOPTERIS flora. A relationship of the Antarctic lands to the southern continents is still indicated to a certain extent by the submarine topography. Their efficiency as a bridge in Permian time is almost beyond question; and it is, perhaps, reasonable to assume that they are parts of a great continental aggregation, essentially constituting, in a broad sense, a greater "Gondwana-land," of which Australia and southern South America were perhaps but lobes.

At this great length of time, since the Paleozoic, and under the conditions of lack of Antarctic geological information a delineation of southern continental outlines is largely mere guesswork. It does not appear to the writer as necessary or even justifiable greatly to interfere with the main basins of the south Atlantic Ocean or seriously to threaten the existence of the Indian Ocean. The oceanic displacements involved in postulating so great southern land masses would seem to be in part compensated by the smaller proportions of the Permian land areas not only in South America, but in the other continents.

The continued efficiency of the Antarctic land connection in Mesozoic time is attested by the relations of both land plants and vertebrates in the Southern Hemisphere. As bearing distinctly on this subject from the paleobotanical standpoint one need cite only the occurrence of the Rajmahal flora in Argentina as reported by Professor Kurtz.[1] The great extent of the land surfaces, whether com-

[1] The intimate relationships of the Mesozoic and even of the Tertiary vertebrates of Patagonia to those of the eastern hemisphere have been abundantly shown by Professors Ameghino and Scott.

bined in a single continent or included in several very closely situated land masses comprising the greater "Gondwana-land" of Permian time is also indicated by the vast areas of freshwater sediments unconformably laid down in the Indian, South African, and South American regions.

AGE OF THE GANGAMOPTERIS FLORA

It has been shown that the GANGAMOPTERIS or Lower Gondwana flora dates from the time of the glacial bowlder conglomerates—i. e., from the glacial period itself. Though many geologists and paleontologists appear still to disagree as to the geological time of this date, the criteria are sufficient to fix it within very close limits. The refrigeration cannot have antedated the flora at Tete[1] on the Zambesi, which is of middle or lower Stephanian age. So also the very late Coal Measures plants from the province of Shansi in China[2] and the flora representing a horizon close to the base of the Permian at Jantai in Manchooria[3] show no important climatic differences from the topmost Carboniferous floras of western Europe. On the other hand the mingling of GANGAMOPTERIS and Glossopteris species with *Callipteris*, *Lepidodendron*, and Zechstein animal remains in northern Russia[4] show that the flora was well established and becoming enriched at that time. The invertebrate fauna of the marine beds associated with the conglomerates in New South Wales are regarded by Frech[5] as Permian. The introduction of Lepidodendron, Lepidophloios, and Sphenophyllum in the GANGAMOPTERIS flora probably occurred before the close of the Rothliegende. It becomes most highly probable, therefore, that the refrigeration attending the birth of the flora was consequent to the great terrestrial uplift and withdrawal of the sea at the close of the Carboniferous or at the beginning of the Permian. The flora may accordingly be regarded as dating from the close of the former. The approximate equivalences of the formations, so far as recognized, in the at present detached areas of

[1] Zeiller, *Ann. d. Mines* (2) Mem. Vol. IV, 1883, p. 594.

[2] Schenck, in Von Richthofen: *China*, Vol. IV, 1883, p. 209. Also Abbado, *Pal. Italica*, Vol. V, 1900, p. 125.

[3] Zalessky, *Verh. k. min. gesell.*, St. Petersb. (2), Vol. XLII, 1905, p. 385.

[4] Amalitzsky, *Comptes Rendus*, Vol. CXXXII, 1901, p. 591.

[5] *Lethaea palaeozoica*, Vol. II, Lief. 4, 1892, p. 590.

PERMO-CARBONIFEROUS FORMATIONS OF THE GANGAMOPTERIS PROVINCE

		India	Queensland	N. S. Wales	Victoria	Tasmania	S. Africa	Argentina	Brazil
Mesozoic	Cosmopolitan Flora	Umia Jabalpur Kota-Maleri Rajmahal	Ippswich	Up. Clarence Hawksbury (glacial)	Bellarine Coals	Upper Jerusalem	Cave ss. Red beds		São Bento Serra Geral Botucatú
		Panchet	Burrum c.	L. Clarence			Stormberg	Cacheuta	R. do Pasto
Up. Permian	Gangamopteris Flora	Damuda Raniganj Barakar	Bowen River Coals	Ballimore and Newcastle coal series	Baccus Marsh Series	Mersey and Porters Hill	Beaufort series	Red beds and sandstones	Passa Dois s. Rocinha ls. Gray & variegated sh. and ss. Iraty shale
L. Permian		Karharbari		Upp. Marine (glacial)			Ecca	Coals and shales	Tubarão Series Estrado N. Minas ss.
		Talchir (glacial)	Bowen R. Marine (glacial)	Greta coals L. Marine (glacial)	Baccus M. Conglomerate (glacial)	Upp. Marine with coals (glacial)	Dwyka conglomerate (glacial)	Basal conglomerate (glacial)	Orleans cgl. (glacial) ss. and sh. (local)
Pre-Permian	Cosmopolitan Flora	Unconformity	Unconformity	L. Marine Unconformity	Unconformity	Marine Unconformity	Unconformity Tete Stephanian Unconformity ?	Unconformity	Unconformity
			L. Carboniferous Devonian	L. Carboniferous Devonian	L. Carboniferous Devonian		Witteburg Devonian	Retamito Devonian	Granites and Devonian

the GANGAMOPTERIS flora are indicated in the accompanying table. No attempt is therein made to include or show the equivalents of all the Mesozoic formations.

ORIGIN OF THE GANGAMOPTERIS FLORA

The types composing the GANGAMOPTERIS flora belong, as Professor Arber[1] has so well shown, almost exclusively to families already well known in the cosmopolitan flora. They constitute genera or species more or less closely bound to their northern relatives, though often differing much in form and aspect. In general they appear simpler in figure, with a tendency to thickness and rugosity of leaf that may indicate either a xerophytic or pseudoxerophytic condition. On the whole the aspect of the plants distinctly suggests environmental conditions unfavorable to luxuriant plant growth. That the development of this flora was directly consequent to a Permo-Carboniferous period of regional refrigeration is now no longer questioned. In its purest and simplest composition, and with remarkable uniformity, it is found in India, Austraila, South Africa, and South America immediately above apparently contemporaneous formations bearing evidence of the work of ice. The conditions which brought the new flora into being banished or exterminated the Cosmopolitan or northern Permo-Carboniferous flora from the GANGAMOPTERIS province. The early return of a few of the hardier Lycopodineous forms in Argentina, Brazil, and South Africa, has already been mentioned. Most of the former plant population of the province died in exile, and only their posterity, especially among the Cladophleboid ferns and the Araucarian, Ginkgoalean and Cycadalean gymnosperms were able to traverse the lost territory and contest the GANGAMOPTERIS occupation.

It is not probable that any serious hindrance other than altitude or climate seriously opposed the return of the northern flora to the GANGAMOPTERIS province in either the Western or the Eastern Hemisphere. The early return of certain Lepidophytes to the Brazilian and South African regions and the invasion of the Russian area by some of the older Gondwana elements is evidence of the efficiency of

[1] *Catalogue of the Foss. Pl. of the Glossopteris Flora in the Department of Geology in the British Museum*, 1905, p. xx.

the land route. The absence of the northern flora from the series above the glacial deposits can therefore be due only to the uncongeniality of the province to that flora.

CAUSES OF THE PERMO-CARBONIFEROUS GLACIATION

So varied as well as great are the geological changes since Paleozoic time that the exposure, at this late date, of an ancient glaciated floor at even a few points is fortuitous. Yet proofs of Permo-Carboniferous land ice movement have been observed over an area more than 800 miles in length and 400 miles in breadth in South Africa,[1] while glaciated material is seen here and there over a very much larger territory. In Victoria the till and bowlder beds compose the greater part of a section about 1,700 feet in thickness. Bedrock striation, the work of grounded icebergs, if not of subaerial ice, is seen in India, and several provinces of Australia as well as in Tasmania. The GANGAMOPTERIS province undoubtedly witnessed Permo-Carboniferous glacial action many times greater than that which occurred in the Northern Hemisphere during Pleistocene time.

However complete the unanimity as to the fact of Permo-Carboniferous glaciation in the GANGAMOPTERIS province, there is little agreement as to the causes of that remarkable episode. The information obtained from South America both extends and defines more clearly the problem, though in the solution of the latter the testimony of the new data is perhaps chiefly negative.

So long as the glaciation was supposed to have been confined to the Indo-Africo-Australian quarter of the earth a shifting of the axis so as to place the pole in the Indian Ocean was urged in explanation of the regional refrigeration. The recognition of the glaciation in South America and as far north as latitude 28° in that continent seriously modifies if it does not completely destroy this hypothesis.

Depletion of atmospheric carbonic-acid gas.—Of the other hypotheses that which seems by far most nearly to meet the situation has for its essential condition loss of heat on account of a depletion of the atmosphere in carbonic dioxide consequent to great coal and limestone deposition during the Carboniferous epoch. Co-operative and

[1] Wm. M. Davis, *Bulletin of the Geological Society of America*, Vol. XVII, 1906, p. 377.

almost co-ordinate with this atmospheric impoverishment were, in the judgment of the writer, the size and height of the glaciated land masses.

That there was a change in the composition of the atmosphere toward the close of the Carboniferous is now generally admitted. Whatever may have been the effect of the limestone deposition, it is certain that the carbon extracted from air and sea and stored away in the coals and bituminous shales of the Paleozoic Coal Measures was far greater in amount than that in any other similar series laid down during geological time. Abundant red beds and oxidation bear evidence of the concomitant high proportion of oxygen in the atmosphere and of rapid evaporation.

Great extent of southern lands.—Concerning the size of the land masses the testimony is hardly less clear. It has been shown that the conditions of land plant and land vertebrate distribution call for the extension of land surfaces in one continuous or in several nearly contiguous continents including large portions of India, Australia, New Zealand, South Africa, and southern South America. It is probable that this connection was accomplished through the medium of an Antarctic continent, of which Australia, South Africa and a part of South America were possibly but lobes. The surviving or vestigial areas preserved in India, Africa, and South America bear evidence of the existence of enormous drainage surfaces on which the great series[1] of conglomerates and coal measures of the Gondwanas in India, the Dwyka and Ecca series in South Africa, and the Permo-Carboniferous of many states in Argentina and Brazil were laid down as fresh-water formations. The magnitude of the land ice action itself argues for extensive land surfaces in those regions.

Problem of tropical glaciation.—The most difficult feature of the problem relates to the geographical distribution of the glacial evidence. In India distinct ice work is found at 18° N.—i. e., within the tropics—and bowlders regarded as glacial have been found at 32° N., in the Salt Range. The Australian region within which glacial material is found extends from 20° 30′ S. to 42° S., and ranges

[1] In South Africa 4,000 feet; about 10,000 feet in New South Wales; 1,200 feet of the Talchic conglomerate, while the Damuda series alone is said to measure 10,000 feet in India.

through about 35° of longitude. In South Africa glacial material has been found from 25° to 33° S. and through 11° east and west, while in South America it appears to occur as far north as 30° S. In Australia there is proof of a recurrence of glaciation with a thin interglacial series (Greta), 230 feet in thickness including coals, between the bowlder beds.

Exaggerated temperature effects of elevation.—The occurrence of glacial phenomena within the tropics was presumably due in part to an extension of the southern cold with the favoring assistance of ocean currents and perpetual atmospheric "lows," resulting in part from continental relations and topography. The writer is strongly disposed further to attribute a very important part in the refrigeration, and more particularly the singular localization of the latter, to the height of the land on which the glaciers developed. Mention has already been made of the fact that the great coal measures series of the Gondwanas, of South Africa, and of South America are vast fluviatile or lacustrine deposits many thousands of feet in thickness, resting unconformably on old erosion basin floors. The enormous accumulations of coarse conglomeratic material in the eastern regions testify to the steep gradient of the drainage systems. The presence in nearly all regions of the great unconformity is itself evidence of the vigor of the post-Carboniferous uplift in the GANGAMOPTERIS province. In Africa and South America, at least, large portions of the land masses probably stood at a considerable elevation during glaciation. It is not clear that in Australia or India the source of the ice was near sea level, though on both the latter there is abundant evidence of the deposition of bowlders dropped from floating ice. Currents of cold water sweeping along the Antarctic continent may well have carried icebergs for long distances to the north in the Australian region.

A relatively high altitude for the areas of ice accumulation would not only enormously assist in explaining the peculiar geographical distribution of the ice phenomena, but it would seem to offer a satisfactory accounting for the differences in climate, as indicated by the floras, between the Northern and Southern regions. It has been urged by Chamberlin[1] that a diminution of the CO_2 of the atmosphere, with

[1] *Journal of Geology*, Vol. VII, 1899, pp. 545, 667, 751.

its attending decrease of humidity, would result in a marked increase in the difference between the mean temperatures of land and sea, the loss of the sun's heat by the land being greatly accelerated as compared to the lesser loss by the sea; so that despite stronger winds, convection currents, etc., an increasing cold would prevail in the great land areas. If to this principle is added a most important fact, that altitudinal differences in temperature would be exaggerated if the carbon-oxide of the atmosphere were reduced, it will appear probable that partial depletion of the carbonic acid gas might produce greatly magnified effects of cold, with accentuated seasonal differences at relatively moderate elevations in the interiors of the land masses,[1] while the climate near sea level especially in the smaller lands or in proximity to large oceanic bodies, might still be mild and relatively equable. It might thus be possible for the Cosmopolitan flora to survive on the low or base-leveled coasts of the sea-girted northern lands while glacial conditions prevailed at no great elevation in the interior plateaus and subaerial basins of the Southern "Gondwana-land." The writer is therefore disposed to believe that the glaciation in the GANGAMOPTERIS province was secondarily due to the elevation of its land masses to greatly reduced refrigerative altitudes at the time of the post-Carboniferous uplift. The elevation of the southern land masses and their erosion and glaciation are fully demonstrated. The enormous thickness of continental sediments already noted in Africa, India, and Australia, including over 1,200 feet of basal conglomerates alone, is itself evidence of a considerable height of land. In Australia there was probable oscillation and recurrence of glaciation as shown by the intercalation of the Greta coals and shales, the latter inclosing the pure GANGAMOPTERIS flora.

[1] The accelerated decrease of temperature in ascending the atmospheric column occasioned by reduction of CO_2 is remarked by Chamberlin. Granting that carbonic acid gas in the atmosphere exerts the influence in arresting the outgoing heat rays attributed to it by Arrhenius and Chamberlin, it is plain that, on account of the extension of its zone far above that of the humidity, an increase or reduction of its volume must also directly and strongly affect the differences in temperature due to differences of altitude. With reference to the climatic effects of changes in the proportion of CO_2 in the atmosphere, the reader is referred to the most valuable discussion published by Professor Chamberlin in Vol. VII of the *Journal of Geology*, 1899, or the second volume of the *Geology* published (1906) by that author in collaboration with Professor R. D. Salisbury.

SURVIVAL OF NORTHERN, "COSMOPOLITAN," TYPES

The survival, in the northern province, of the Cosmopolitan, Carboniferous flora, which had been exterminated from the greater part, at least, of the GANGAMOPTERIS province, and its metamorphism to the Cosmopolitan Permian flora, was presumably due to the generally low base-leveled state of the northern lands and the growth of the plants near tide level in regions bordering great bodies of water. The greater retention of the sun's heat by the sea and the greater humidity would co-operate with the low altitudes to neutralize the effects of atmospheric carbonic acid reduction. The contrast with the climate of the basins in the interior of the more elevated GANGAMOPTERIS (Antarctic) continent could not fail to be great. It is worthy of note in this connection that in general the floral changes in passing to the Permian are least marked, the number of surviving later Carboniferous species being greatest, in those northern regions in which the post-Carboniferous uplift was least and there was less withdrawal of the sea. The best-marked illustration of this is furnished by the Appalachian trough in which the floral change is relatively gradual, the more characteristic Permian species being probably migrant from some more strongly affected region. The early moderation of the climate in Brazil so as to permit the return of a few hardy northern types and the enlargement of the GANGAMOPTERIS flora in other regions by the mingling of northern derivatives were presumably due to subsidence under loading of the basins; the general extension of the marine surface in the upper Permian; and, possibly, to a direct carbonic acid contribution attending the great vulcanism of the Permian.

The flora of the Upper Permian is known in but few parts of the earth, but it is found that early in the Zechstein GANGAMOPTERIS and northern Permian elements mingled in the basins of northern Russia and the Altai; the northern Cycad, Pecopteroid, and Coniferous elements had already invaded the GANGAMOPTERIS province, and from this mingling was developed a group which survived as the nucleus of a new world-wide Cosmopolitan flora, that of the Older Mesozoic.

STRATIGRAPHIC RESULTS OF A RECONNAISSANCE IN WESTERN COLORADO AND EASTERN UTAH[1]

WHITMAN CROSS

One of the principal features of interest in the study of the sedimentary formations of the western mountain slopes of Colorado is their correlation with the formations of the Plateau Province to the west. I have already introduced the discussion of this subject in an article on the Red Beds of Colorado (**8**)[2], but without first-hand information as to the Plateau country. I am now able to review and affirm the correlation there suggested, on the basis of observations made during the summer of 1905, in the course of a reconnaissance from Mancos, on the southwestern flank of the San Juan Mountains, in Colorado, to the vicinity of Moab, on Grand River, in Utah, returning to the northern slope of the San Juan at Montrose. Other members of the party engaged in this reconnaissance were Messrs. L. H. Woolsey, W. H. Emmons, and Geo. F. Kay, all of whom had seen, or were to see later in the season, the stratigraphic succession of formations in the San Juan region. I wish to acknowledge my indebtedness to all these gentlemen for observations recorded with my own in the following pages.

Itinerary.—The party proceeded west from Mancos to Cortez, in the Montezuma Valley; thence northwesterly across the headwaters of various branches of Montezuma Creek to the northeast base of the Abajo or Blue Mountains, in Utah. From this point the route northward lay mainly in Dry Valley which extends nearly to the La Sal Mountains. This part of the journey was near the line followed by Newberry in 1859 (**28**). Turning westward down Spanish Valley to Moab, extensive sections were examined on both sides of Grand River. From Moab we proceeded up the Canyon of Grand River, some 20 miles, and then turned east, passing over the northern slopes of the La Sal Mountains, and thence south through Sindbad and

[1] Published by permission of the Director, U. S. Geological Survey.

[2] Numbers in parentheses refer to the bibliographic list at the end of this paper.

Paradox Valleys. The Dolores River was crossed in Paradox Valley and from that point the route turned again northward following the crest of Uncompahgre Plateau to Unaweep Canyon, the remarkable transverse gorge examined by Peale (**29**). The section exposed in West Creek near Dolores River was studied in some detail. From Unaweep Canyon we retraced our course along the Uncompahgre Plateau and passed down its eastern slope to Montrose. During this journey, of about 450 miles, occupying 30 days, excellent opportunities were presented for observing the stratigraphic relations of formations ranging from the Pennsylvania Carboniferous to the Mancos shale of the Cretaceous.

It will be a great aid to the reader in comprehending the significance of the recorded observations if he will refer to Sheets XIV and XV of the Hayden *Atlas of Colorado* and adjacent parts of Utah, which represent the whole of the area traversed, with the exception of the vicinity of Moab.

GENERAL CORRELATION OF FORMATIONS

The plan of presentation will be to take up the formations of each system in turn and give the evidence which identifies the stratigraphic units adopted in the Colorado folios with certain ones found in the Plateau region, with suggestions, more or less definite as the case may be, as to correlation with the terminology of Peale, Holmes, and other geologists who have written upon the region visited. The table of correlation appearing on the following page is presented as a guide in following the discussion.

CRETACEOUS FORMATIONS

The floor of the main plain or plateau between the San Juan Mountains and Grand River Canyon in Utah, variously designated on the Hayden maps, in adjacent areas, as San Miguel Plateau, Dolores Plateau, and Great Sage Plain, is immediately underlain by the Dakota sandstone. Speaking of the very district traversed by our party on the outward journey, Holmes remarks that "over hundreds of square miles these sandstones lie comparatively unbroken, while the loose series of shales above have been swept off like so much dust from a great floor" (**17**, p. 259).

CORRELATION OF FORMATIONS

San Juan Folios, U. S. G. S.			Peale	Holmes	Powell
Cretaceous	Mancos				
	Dakota		Dakota or Upper Dakota	Upper Dakota	Henry's Fork
Jurassic	Gunnison	McElmo	Lower Dakota	Lower Dakota	Flaming Gorge
			Jurassic		
		La Plata	Triassic	Triassic	White Cliff
Triassic	Dolores				Vermilion Cliff
Carboniferous	Permian ?	Cutler	Permean Permo-Carboniferous, or Upper Carboniferous		Shinarump Group (All assigned to Triassic)
	Pennsylvanian	Hermosa	Middle Upper Carboniferous		Aubrey

The continuity of exposures, the persistence of lithologic characters, and the simplicity of stratigraphic relations place it beyond question that the section under discussion has for its upper members the Dakota sandstone and a variable remnant of Cretaceous shales, everywhere of the same general characteristics. The shale formation has been named after the town and valley of Mancos, our starting point, and I am aware of no reason why that name should not apply to the portions of that formation remaining above the Dakota, over the entire Plateau Province east of the Colorado and Grand Rivers, if not, indeed, still farther westward.

The formation here called Dakota is that designated as "Upper Dakota" on Sheets XIV and XV of the Hayden *Atlas of Colorado*, covering the portion of Colorado and Utah with which this discussion has to do. The "Lower Dakota" of those maps was a division established by Holmes for strata below the commonly recognized Dakota, as will shortly be explained.

While this reconnaissance was in progress Stanton and others were demonstrating that the beds hitherto referred to the Dakota to the east of the mountains, in the Arkansas Valley, were in part of the Comanche or Lower Cretaceous Series (**36**). Our observations were not directed to this point, but a re-examination in 1906 of the Dakota on the south flank of the San Juan failed to reveal ground for assigning any part of the formation called the Dakota in the San Juan folios to the Comanche Series.

JURASSIC FORMATIONS

All geologists who have examined the Mesozoic section of western Colorado have been impressed with the strong lithologic resemblance exhibited by several hundred feet of strata, occurring immediately below the Dakota to the fresh-water Jurassic beds found along the eastern base of the Front Range and characterized by the wonderful Dinosaurian fauna exploited by Marsh and others. With one exception, to be considered below, this lithologic similarity and corresponding stratigraphic position have been considered sufficient to warrant the assignment of the western slope beds to the Jurassic.

The first to give a formation name to those strata was Eldridge (**13**), who called them the Gunnison formation. In the San Juan region it was found better to divide the Gunnison into the McElmo and La Plata formations, the former to include the alternating sandstones and variously colored marls and shales of the upper part of the section, and the latter the heavy sandstones of the lower portion.

THE McELMO FORMATION

Before the McElmo beds were so named (**3**) they had been studied in the Telluride quadrangle at the head of San Miguel and Dolores Valley, and had been traced for some distance down each stream.

They are continuously exposed down the canyon of the former to the Dolores River and have a wide distribution in the Uncompahgre Plateau, about the La Sal Mountains and in the lower Dolores and the Grand River valleys. This is clearly stated by Peale in the *Report* for 1875 (**29**). But the Hayden map covering the area just mentioned shows "Lower Dakota" beds as present beneath the plateau-making Dakota proper, and in Peale's *Report* for 1876 (**30**) he divides the

beds formerly called Jurassic into "Lower Dakota" and Jurassic, consistent with the map. It may be well to make a summary statement in this place concerning the origin and application of the term "Lower Dakota," since the use of the Hayden map is rather confusing without explanation. Moreover, the McElmo beds were named from a locality where the Hayden map shows no Jurassic beds.

While surveying the Rico quadrangle the Dakota and subjacent strata were traced southwesterly down the Dolores Valley to the great bend of the river, where it turns due north. But a few miles west of that point several branches of McElmo Creek, a large tributary of San Juan River, cut below the Dakota sandstone into the underlying Jurassic beds. Flowing at first in narrow canyons rimmed by the Dakota, these various forks finally widen into valleys presenting broad exposures of the strata in question. In 1897, H. S. Gane, who had been my assistant in the Telluride quadrangle work, traversed the main McElmo Valley from its head to the San Juan River and upon his report the name McElmo was chosen for the Jurassic formation beneath the Dakota.

The Hayden map, Sheet XV of the *Atlas of Colorado*, represents the "Lower Dakota" as the principal formation below the plateau sandstone, in McElmo and Montezuma Valleys and in the adjacent portion of the broad San Juan Valley. Apparently the "Lower Dakota" of that map represents in fact the general distribution of the McElmo formation. No Jurassic formation is shown upon the Hayden map of that region.

This cartographic representation is based on the work of W. H. Holmes, and its explanation is to be found in his report for 1875 (**17**, p. 260). Describing in general terms the section below the Dakota proper Holmes says "The variegated series which succeeds it [downward] I at first felt inclined to call Jurassic, since it resembles so closely the variegated beds that on the eastern slope of the mountains have usually been credited to that age." After mentioning details of differences in lithologic character, Holmes refers to a much more important basis for his conclusion. He states (**17**, p. 261) that: "In Middle Western Colorado Dr. Peale has found Cretaceous fossils in a stratum of sandstone some three or four hundred feet beneath the bed of conglomerate [referring to the basal Dakota conglomerate],

and also beneath a series of variegated beds that resemble these in this section." No mention of even the general character of these fossils is made, nor can I find any further reference to them in the publications of the Hayden Survey. Personal inquiry of both Messrs. Holmes and Peale brings out the fact that after the lapse of many years spent in other lines of work, neither geologist is able to recall the basis for the statement that such fossils had been discovered, nor can records in regard to them be found. As the observations of the last 30 years do not indicate the existence of Cretaceous fossils in the position referred to, it must be assumed that the statement is an error, the origin of which cannot now be fixed.

The McElmo beds in characteristic development were seen by us in Dry Valley and on the eastern flanks of La Sal Mountains, in Dolores Valley, and in many places on Uncompahgre Plateau, as far north as Unaweep Canyon. To the north from that locality Peale refers to the formation as maintaining the same general character. No representative of the Marine Jurassic reported by Powell (**33**) and others from Utah was observed by us.

Rumors of large bones, presumably in the McElmo beds, have come to my attention several times in recent years, but never with exact locality named, and no trace of such remains has been found in the San Juan region.

The McElmo beds of Dry Valley are fossiliferous, locally, at least, as proven by Newberry, who found saurian bones in place at about 500 feet below the Dakota (**28**, p. 91), in the southeastern branch of Dry Valley, named by him Cañon Pintado or Painted Cañon. From Newberry's description of the locality and our own observations of the Cañon Pintado from the mesa to the west, as well as on the route traversed through Dry Valley, it is certain that the saurian bones came from the McElmo. Newberry expressed no positive opinion as to the age of the bone-bearing horizon, but called it "Jurassic(?)" in his "General section of the Valley of the Colorado" (**28**, p. 99).

The saurian bones found by Newberry were described by Cope (**2**, p. 31) as the type of *Dystrophæus viæmalæ*, and were said in positive, but quite unwarrantable, terms to have come from the Triassic, with no suggestion of the provisional assignment to the Jurassic by

Newberry. Cope states that Newberry excavated the bones of Dystrophæus "from the red and green rocks usually referred to the Trias, hence from the same formation which yielded the *Typothorax* already described." The *Typothorax* in question was found in New Mexico with belodont crocodile and other forms almost demonstrating that its horizon is the fossiliferous zone of the Dolores Triassic formation, the place of which in the Grand River section is nearly, or quite, 1,000 feet below the McElmo beds, as will be shown in a later section. Cope adds emphasis to his error as follows: "More than usual interest attaches to this fossil. It is the first one found in the Triassic beds of the Rocky Mountain region. . . . ." "The rock is described by Professor Newberry as the same as that which I have identified in New Mexico as the Trias and is of the usual red color" (**2**, p. 36*a*). In harmony with the occurrence of *Distrophæus viænalæ* in the McElmo beds it has recently been pointed out by F. von Huene that its affinities are Jurassic rather than Triassic (**20**).

That the McElmo beds contain the vertebrate fauna of the "*Atlanta-saurus* beds" of Marsh has been demonstrated by Riggs who discovered many dinosaurian remains in that formation near the junction of the Grand and Gunnison Rivers at the northeastern base of the Uncompahgre Plateau (**34**, p. 651). While this vertebrate fauna has not as yet been described, it is referred to by Riggs as clearly the same which characterizes the Jurassic beds of Wyoming and the eastern base of the Front Range in Colorado. It is said that "Representatives of a single genus (*Morosaurus*) have been observed to range through the entire series," meaning a section some 500 or 600 feet in thickness below the Dakota.

It is to be regretted that Riggs did not make the importance of his discovery in the correlation of the Colorado Jurassic more evident to the general reader by a reference to the literature concerning occurrences of supposed Jurassic in western Colorado. There is no mention of the beds for which Eldridge proposed the term Gunnison in the Anthracite-Crested Butte folio (1894), nor to my division of the Gunnison into McElmo and La Plata formations in the Telluride folio (1899). Riggs applies the term "Como beds" to the "Dinosaur beds" of Wyoming and Colorado, although Morrison (Eldridge, 1894)

and Gunnison both antedate Como by several years, if I am correct in thinking that the first definite proposition to use Como as a formation name was made by Scott (**35**, p. 477) in 1897.[1]

Beneath the vertebrate-bearing fresh water Jura are 100 to 120 feet of "bluish and grayish gypsum-bearing clays in which thin layers of fine-grained sandstone and nodular ledges of limestone are interspersed." These Riggs refers to the "marine Jura," although they are destitute of fossils. This assignment must be considered questionable in view of the fact that no marine Jurassic beds are known in Colorado except in the northwestern part where they apparently are to be correlated with occurrences in Utah and Wyoming. The few hundred feet of reddish sandstones below the "marine Jura" are referred by Riggs to the Trias, in accordance with Peale's view. This assignment will be discussed in the next section. The underlying pre-Cambrian granite is spoken of (perhaps inadvertently) as "intrusive" in the sandstones.

LA PLATA FORMATION

The term La Plata formation has been applied in the San Juan folios and other publications to the lower part of what Eldridge described as the Gunnison formation (**13**).

The La Plata consists of two massive sandstone members with an intermediate member of more thinly-bedded sandstones and a variable amount of bluish freshwater limestone. The sandstones are commonly not indurated as in the Elk Mountains; instead they are rather friable and crumbling, although of homogeneous texture. Cross-bedding is a marked feature, and not infrequently a massive ledge as much as 100 feet in thickness has no prominent division planes. Of the two sandstone members the lower is commonly thicker and much more massive than the upper. The latter is in fact occasionally thin-bedded and shaly and may be inconspicuous.

The calcareous member is very variable in character. On the San Miguel River, in the Telluride quadrangle, it is in some places

[1] The reference by Knight to the Como beds as *marine* (*American Journal of Science*, 3d Series, Vol. V, 1898, p. 380) is clearly a mistake as he later names the *marine* Jura of Wyoming the Shirley beds, reserving the term Como beds for the *freshwater* strata above the Shirley (*Bulletin of the Geological Society of America*, Vol. XI, 1900, p. 377).

a pure massive blue-gray limestone in several beds and with almost no shale. Usually dark calcareous and bituminous shales and thin-bedded sandstones, with more or less of massive limestone, occur between the two main sandstones and sometimes reach a thickness of nearly 100 feet.

The total thickness of the La Plata formation varies, in the area we have examined, from about 100 feet in the Ouray and Telluride quadrangles to 500 or more in the La Plata mountains, and it is known that to the west all members increase still further in thickness.

The sandstones are almost wholly quartzose, and their normal color adjacent to the San Juan Mountains is white or gray; but yellow, orange, and red tints have been observed in that region. The cement is often calcite.

In the Red Beds paper (**8**) were given the observations of Spencer, who traced the La Plata sandstones to Paradox and Sindbad valleys, west of the Dolores, and of Gane, who followed them down the San Juan Valley to the Colorado Canyon. Both noted the prevalence of orange or pink color in the lower country.

On the strength of these observations and a study of literature it was concluded that "the La Plata Formation is seemingly equivalent to the White Cliff sandstone. Its local assumption of red color has led to confusion with the Vermilion Cliff in certain districts and a reference to the Trias." This correlation is considered to be amply substantiated by the recent observations. As this matter is of much importance to an understanding of Plateau geology the grounds for this correlation will be given in some detail.

The first point to be considered will be the relation of the La Plata sandstones of the San Juan slopes to the "Triassic" of Peale in the Uncompahgre Plateau and lower Dolores Valley. The continuity of the La Plata exposures from the Telluride area northwesterly through the San Miguel Canyon and Plateau to the slopes of the higher Uncompahgre Plateau leaves no room for doubt that the upper part of Peale's "Triassic" consists of the La Plata. Moreover, a careful examination of Peale's descriptions of the "Triassic" sandstone shows that characterization to be fully in harmony with this idea. He repeatedly emphasizes a distinction between the upper, light-colored and the lower dark-red sandstones. To illustrate this

the following quotations among many that might be made will suffice. Speaking of the "Triassic" at the head of the Little Dolores, the north end of the Uncompahgre Plateau, he says: "The upper beds of the formation, as usual, are lighter colored than those below. Near the heads of the creeks they are orange-yellow, becoming pink as we go north. Immediately beneath them we have blood-red sandstones which rest on gneissic rocks (**29**, p. 48). In the Unaweep Canyon he says that: "The white or orange-colored, cross-bedded, massive sandstone forms the top of the series" (**29**, p. 81). And again the expression, "the cross-bedded, white sandstone of the Upper Trias," is used (**29**, p. 82).

In characterizing the sandstones on the west side of the Plateau north of San Miguel River he remarks: "The upper portion of the Triassic beds in this region are light colored; in fact in many places they are almost white, and it is only by noticing their structure, which remains the same whatever the color, and watching the change in color, with their position in relation to the remaining strata, that we can identify them. Another point to be noted here is that they are directly superimposed on the Archean rocks" (**29**, p. 55). This last sentence refers to the unconformity between the La Plata and the red Triassic sandstone, which will be discussed farther on in this paper.

From the Dolores Valley the La Plata sandstones are continuously exposed, through Paradox and Sindbad valleys, around the northern and western slopes of the La Sal Mountains to the broad plateaus bordering Grand River Canyon below Moab. Peale examined this area from the summits of the La Sal Mountains (**29**, p. 60), and Holmes viewed them from the similar commanding peaks of the Abajo group. The simple stratigraphy of the area, as far as the section from the Dakota to the Trias is concerned, was an open book to these experienced field observers, and they agreed in extending the units of the areas they had examined in detail through the low country which was hurriedly traversed by Peale.

As the La Plata formation can be traced to the walls of Grand River Canyon below Moab, there is little room to doubt its further extension to the junction with Green River, some 30 miles, and thence down the Colorado to the mouth of the San Juan Valley, 70 miles further, to the point where it was traced by Gane, as mentioned.

As far as I am aware no geologist has described the wonderland lying between Grand River and the Cretaceous divide between the La Sal and Abajo Mountains since the vivid pen pictures of Newberry in his report of the Macomb expedition (**28**). Nor can one easily equal the clearness with which the broader features of this fascinating region are portrayed. To one familiar with the formations Newberry's descriptions are for the most part easily interpreted.

Descending from the Great Sage Plain, with its Dakota floor, one passes first some 500–600 feet over the steep slope where the soft sandstones and red or green shales of the McElmo occur, but are seldom well exposed. Below them is the upper sandstone of the La Plata, about 300 feet in thickness, which forms low mesas or ridges between the branches of Dry Valley, the main floor of which, over wide stretches, is near the upper surface of the lower La Plata sandstone. The upper member is a fine and even-grained massive sandstone, strongly cross-bedded, of yellowish or pinkish color, and lends itself to a very characteristic sculpturing. We fell at once into the habit of calling this member of the La Plata in Dry Valley the *alcove sandstone*, from the numerous recesses exhibited in nearly all its cliff exposures. Newberry illustrates this feature of a hill called by him "Casa Colorado," and in the files of the Geological Survey is a photograph by W. H. Jackson, clearly of the same subject, reproduced here as Fig. 1.

Certain remnants of the alcove sandstone now standing as isolated hills are very striking. One of these, known as Looking-glass Rock, is situated southwest of the La Sal Mountains near and east of the road from Monticello to Moab. It is represented in Fig. 2. Another remnant of erosion is shown in Fig. 3. Near the base of this knoll a band of marked red color transgresses the stratification very markedly, serving to show the secondary origin of the red color in this case.

The massive character of the upper La Plata sandstone is further illustrated by Fig. 4, representing the cliffs of the upper La Plata in the canyon of Grand River a few miles above the Moab ferry. The incipient alcoves at this point seem largely due to jointing.

The middle calcareous member of the La Plata is apparently represented in Dry Valley by less than 100 feet of thinly-bedded strata, sandstones for the most part, with shaly and impure cal-

careous layers between. The latter are often nodular in development and a pure blue limestone like that of the San Juan region was not seen. In color these beds are apt to be darker red than the massive sandstones above and below, but some layers are gray or yellowish. These beds are seen in Fig. 3 at the base of the sandstone mass.

Below the floor of Dry Valley is the lower La Plata sandstone in a thickness of about 250 feet. It is well shown in Cañon Colorado,[1] (Newberry) and its branches, through which the drainage of Dry

FIG. 1.—"Casa Colorado" (Newberry). In Dry Valley, Utah, near Cañon Pintado. Made of friable sandstones of the upper La Plata formation, Jurassic. Exhibits the alcoves which are very common in this sandstone in the Grand River district. Photograph by W. H. Jackson.

Valley and the southwest slope of the La Sal Mountains enters Grand River.

The lower La Plata sandstone of the Grand River region is more indurated than the upper and is specially distinguished by its cross-bedding. It is light pink or gray, of even fine grain, but is not so notably uniform as the upper. Fig. 5 illustrates a characteristic bank of this sandstone on a small tributary of Cañon Colorado.

[1] The Hayden *Atlas* maps apply this term to the broad shallow part of Dry Valley but on the sketch map of Peale's report for 1875 the name is applied in accordance with Newberry's usage.

Newberry's descriptions and sketches show how strong these characters are in the greatly dissected country adjacent to Grand River.

The base of the La Plata sandstone is probably to be taken as at the horizon where the light-colored, cross-bedded, massive strata give way to dark red sandstones of the Trias. The unconformity or stratigraphic break below the La Plata, discussed in the next section, is not always in evidence in the Plateau country and indeed there is in many places as near an approach to perfect conformity as is commonly found within a given formation between sandstones of different textures.

On the northern side of Cañon Colorado, near its head, the La Plata rests on thin-bedded reddish sandstones of fine grain near the top of which are calcareous layers. Some of the beds contain small chert fragments. In Fig. 6 is shown the nearly white, cavernous, cross-bedded strata, at the base of the La Plata, immediately beneath which are the strongly calcareous sandstones of dark-red color which on weathering yield large nodular masses, such as those in foreground. This is believed to be the line between the Jurassic and Triassic beds at this point.

The continuity of the La Plata sandstone from the San Juan Mountain flanks down the Dolores and San Miguel valleys, around the La Sal Mountains to Grand River Valley, may be said to be perfectly plain and incontestible. In this distance the most notable change in the formation is its increased thickness. The massive texture and even grain of many strata, cross-bedding, variation in color, and other marked features are but emphasized by the greater, volume. The intermediate strata are most variable in character, yet everywhere the two great massive sandstone members are separated by beds distinguishable through their thin bedding, darker color, and richness in calcareous cement or development of limestone.

From the district covered by our reconnaissance the ledges of gray, pink, or orange La Plata sandstone can be seen stretching to the west and south into the belt traversed by Green and Colorado Rivers, where Powell has described the White Cliff sandstone. This great unit in the Plateau country section was never described accurately nor in detail for any given locality, but there seems to be no ground for questioning the assertion of Powell that this formation is continu-

ous with persistent characters from northeastern Utah to the great esplanade bordered by the White Cliffs in southern Utah facing the Grand Canyon. The characters of the White Cliff repeatedly emphasized are its massiveness, "oblique lamination" or "false stratification," and its white, golden, orange, or light-red colors, which are so brilliant in the desert air.

The upper boundary of the White Cliff is the basal marine limestone of the Flaming Gorge Group, of Powell (**33**). The lower

FIG. 2.—Looking-glass Rock. Near southwest base of La Sal Mountains, Utah, to east of road from Monticello to Moab. Formed of alcove-making upper sandstone of La Plata formation. At rear of recess is an opening through to other side of rock. The scale is indicated by figures of two men outlined against sky through opening.

boundary is less clearly defined in the statements of Powell and others, but, with recognition of the stratigraphic break soon to be mentioned and the marked color line apparently everywhere present at the summit of the Triassic sandstones, it may be hoped that no great difficulties in drawing the base of the White Cliff will be experienced when the attempt is seriously made.

UNCONFORMITY BELOW THE LA PLATA SANDSTONE

The far-reaching unconformity below the fresh-water Jurassic beds of central Colorado, by which they overlap all older Mesozoic

and Paleozoic beds and in many places rest on the pre-Cambrian granites and schists, is well illustrated by the Hayden maps. This overlap is particularly well exhibited in the southern Elk Mountains and some of its details are shown in the Anthracite-Crested Butte folio (**13**).

The fact that no Paleozoic formations are present in the Uncompahgre Plateau was recognized by Peale and expressed on the Hayden map. If, however, the greater part of Peale's "Triassic" in that area be now referred to the La Plata Jurassic, as has been done in the preceding discussion, the question arises as to whether evidence of erosional unconformity between the La Plata and the underlying Dolores Triassic exists in that area or not. Our observations on this point were quite limited but tend to show that such a break does occur. It is certain that in the vicinity of the Unaweep Canyon the dark-red Triassic strata are much thinner than in the Dolores Valley to the west and this decreased thickness appears to be principally due to erosion of the massive red sandstone forming the upper part of the Triassic.

On the north side of West Creek, which is the western stream flowing out of Unaweep Canyon, Messrs. Emmons and Kay found the La Plata to rest on granite near the shore line of the Permian (?) beds which will be discussed in another part of this article. At the head of West Side Creek a few miles south of the Unaweep the pink La Plata sandstone rests on thin-bedded sandstones and shales belonging to the lower part of the Dolores formation, as shown by the pressence of the fossiliferous "Saurian conglomerate." Near the head of Atkinson Creek on the western side of Uncompahgre Plateau, the La Plata seems to rest on gneiss, according to the statement of Peale cited on p. 643.

These facts and the evident variation in thickness of the massive Dolores sandstone, which we noticed at many places, seem to speak for a relation of the La Plata and Dolores very similar to that existing on the western and southwestern slopes of the San Juan Mountains. But much more careful observation is needed in the Uncompahgre Plateau to determine to what extent the absence or variable thickness of the Triassic beds is due to pre-La Plata erosion. Personally, I believe that the Triassic beds were originally deposited over the Uncom-

pahgre Plateau and indeed all of western Colorado, and that they were in some places entirely removed by the erosion under discussion, but this view is not yet supported by enough evidence to warrant a positive assertion.

FIG. 3.—A remnant of upper La Plata sandstone in Dry Valley, Utah. The lower massive sandstone is zone generally characterized by alcoves. The weathering forms shown in cap of hill are very characteristic.

TRIASSIC FORMATIONS

Immediately below the White Cliff sandstone of the Plateau country comes another wonderful formation named by Powell the Vermilion Cliff sandstone (**31**) which has been recognized by Gilbert, Dutton, and other explorers of the region. Its continuity from the Uinta Mountains to the Vermilion Cliff, which forms the next great step below the White Cliff, facing the Grand Canyon of the

Colorado, is unquestioned, and all observers have referred it to the Trias. It is characteristically developed on Grand River.

Below the Vermilion Cliff sandstone of the classic Plateau section comes a series of beds originally called by Powell (**33**) the "Shinarump group," and for it the early observers claimed the same widespread distribution as for the overlying formations. Referred as a whole to the Trias by Powell, it was long ago shown by Walcott (**37**) that the lower portion of the Shinarump group of the type locality was Permian (?). Our observations on Grand River show that the strata below the Vermilion Cliff sandstone, corresponding in position to the Shinarump, are of very different character from those of the typical section of that group.

In the Red Beds paper (**8**), I suggested that the Dolores formation of Colorado includes diminished equivalents of the Shinarump group and Vermilion Cliff sandstone of the plateau province. With qualifications as to the Shinarump this view has been substantiated. The importance of the relations discovered on Grand River requires a preliminary review of the essential features of the Dolores formation as an aid to a comprehension of the new data.

The Dolores formation of the San Juan region.—The name Dolores Formation has been proposed for the Triassic portion of the Red Beds of southwestern Colorado. It is now known to embrace but a few hundred feet of strata, with stratigraphic breaks, represented in some localities by definite unconformities, both above and below. In the San Juan country the Dolores consists of an upper, dark red, fine-grained sandstone, of variable thickness, in consequence of the pre-La Plata erosion just discussed, and of a lower sparingly fossiliferous succession of sandstones, shales, and peculiar conglomerates.

The thoroughly diagnostic element of the Dolores formation is a certain kind of fine-grained reddish or grayish conglomerate, occurring constantly at its base and repeated in variable development at several horizons in the lower 200 or 300 feet of sandstones and shales. The pebbles of these peculiar conglomerates are commonly very small in some places, resembling pisolitic grains, and appear to be derived from the breaking-up of limestone beds in process of formation; at least, they are not from the bluish fossiliferous limestones of the

Carboniferous section and they are rarely associated with pebbles of other rocks.

In this limestone conglomerate occur almost everywhere small fragments of bone and occasional teeth, vertebrae or other small bones, which have been identified by Lucas as belonging to belodont crocodiles, or to dinosaurs of megalosauroid types. Unios, gasteropods, and plant remains are sparingly associated with the vertebrates.

In the Red Beds paper (**8**) the wide distribution of this fossil-bearing conglomerate was pointed out and the even greater extent

FIG. 4.—The La Plata sandstone. In Canyon of Grand River a few miles above ferry at Moab, Utah. The massive beddings are specially marked in this vicinity. Through irregular jointing rude alcoves have been initiated, suggesting one of the processes involved in their formation.

of the fauna it carries. It is necessary here merely to repeat that the peculiar conglomerate with its upper Triassic fauna, marks a horizon of great importance in the stratigraphic column of the Plateau country and the adjacent mountain slopes. The importance of this horizon is further emphasized by the fact that at Ouray, on the north flank of the San Juan Mountains, the "saurian conglomerate" is found to rest unconformably on the Permian (?) red beds and on the fossiliferous Pennsylvanian section below them, testifying to an important stratigraphic break.

Statement of new observations.—In the Grand River Valley a deep red sandstone, which is clearly the Vermilion Cliff, occurs everywhere in its appropriate place beneath the White Cliff or La Plata sandstone. It was first noted by us in the canyon which appears to be the Cañon Colorado of Newberry, where it presents the aspect shown in Fig. 7—the point of view being within a few yards of that of Fig. 6. The massive wall of this canyon is of a fine-grained, dull, deep-red sandstone, about 200 feet in thickness. The thinner-bedded strata, seen in the view above the massive portions, are of a similiar dark-red color. The basal beds of the La Plata are represented in the knoll on the sky line at the left hand.

The dark-red sandstone seen in the gorge of Fig. 7 has ample opportunity to display its cliff-making capacity in the Grand River Valley, as illustrated in the views of Figs. 8 and 9. The massive sandstone is there seldom more than 200 (?) feet thick, but a vertical jointing, common in the formation, leads to vertical cliffs in many places. As noted by Powell and Dutton the more massive part is almost always overlain by about 100 feet of beds of nearly identical character except for the thin-bedding and local tendency to shaly development. Similar strata underlie the cliff-making portion of the formation, as seen in Figs. 8 and 9.

Not more than 100 feet below the cliff sandstone there occurs on Grand River a thin conglomerate, chiefly of limestone, carrying sparingly, but constantly, fragments of bones and teeth of belodont crocodilean or dinosaurian animals. Both in details of character of the conglomerate and of the fossils it carries, as well as in stratigraphic position, this stratum is clearly identical with that at the base of the Dolores formation in the San Juan region. It is present in corresponding position wherever we examined sections carefully, near Moab, in the Grand River Canyon some miles above Moab, on the north slope of the La Sal Mountains, in Paradox Valley, and on West Creek.

The assertion that the fauna contained in the Triassic beds of Grand River is identical with that occurring in the Dolores formation of Colorado is frankly not supported positively by a large amount of evidence in the form of identifiable fossils. On the east side of Grand River near the road to the ferry, Mr. Kay obtained a vertebra con-

cerning which Mr. J. M. Gidley of the U. S. National Museum reports that "though somewhat crushed and weathered, it is recognizable as belonging, probably, to a Triassic form of carnivorous Dinosaur, although it may possibly be referable to a genus of Belodont. It is certainly reptilian and of a more advanced type than any I know from the Permian."

On West Side Creek, a branch of West Creek, where the Trias is represented only by its lower beds, resting on the Archean (see p. 648),

FIG. 5.—This cross-bedded lower La Plata sandstone. View in a ravine tributary to Cañon Colorado. This cross-bedding stands out prominently in most cliff exposures.

a fragment of bone was found in the limestone conglomerate, which Mr. Gidley considers with reasonable certainty to be "a portion of a fibula (lacking the distal end) of a carnivorous Dinosaur probably of Triassic age."

Ill-preserved Unio shells were found in association with the vertebra mentioned. Much better material was obtained in 1901 by Mr. L. M. Prindle, now of the U. S. Geological Survey, in certain of the reddish sandstones between the Vermilion Cliff and limestone con-

glomerate, and through his kindness I am able to give the report made upon these fossils by Mr. T. W. Stanton, as follows:

"The collection of invertebrates collected by Mr. L. M. Prindle contains many good casts and imprints of Unio, apparently belonging to three or more species. These are comparable and possibly identical with *Unio cristonensis* Meek, *U. dockumensis* Simpson, and *U. dumblei* Simpson, all of which come from supposed Triassic beds. *Unio cristonensis* was described with two other species from fragmentary specimens obtained by Cope on Callinas Creek, New Mexico. The Moab specimens are much larger than the types but they agree in outline and general proportions. The other two species above mentioned were obtained by the Texas Geological Survey in the Dockum beds of northwest Texas. These beds have yielded four species of Unio, which, with the three species from about the same horizon in New Mexico, are the oldest known representatives of the genus. The species in the Moab collection seem to belong to the same Unio fauna.

That in this vicinity a stratigraphic break of much importance occurs just below the "saurian conglomerate," as it has been called in the San Juan region, is evident on Grand River and at other places. On the west side of Grand River opposite Moab the bone-bearing conglomerate is separated from fossiliferous Pennsylvanian beds by only about 50 feet of shaly sandstone, and it is possible that these beds also belong to the Pennsylvanian series. Details of the section at this point are given on p. 669.

Near Moab, on the northeast side of Spanish Valley, a poorly exposed section reveals about 250 feet of strata, mainly reddish sandy shales, between the "saurian conglomerate" and the uppermost Pennsylvania limestone. On Grand River about 1 mile above the Moab ferry the "saurian conglomerate" reappears above the level of the river, and, as it rises gradually to the northeast for several miles, a larger and larger section of the pre-Dolores strata is exposed, but nowhere so far as our observations go, do the Pennsylvanian beds appear, all the sub-Dolores section belonging to the upper (Permian?) series of the Carboniferous. This is itself evidence of a great break immediately below the "saurian conglomerate." That the break represents uplift and erosion producing angular unconformity is well illustrated on both sides of Grand River about 10 or 12 miles northeast of the ferry and just below the mouth of Castle Creek, a stream heading on the west side of the La Sal Mountains. Fig. 8

illustrates this unconformity, which may be traced for about half a mile, and it was estimated that at least 600 or 800 feet of beds are visibly truncated by the conglomerate in one continuous exposure. The occurrence of an extensive section of gypsiferous sandstones and shales beneath the Dolores conglomerate in Fisher Valley on the northwest side of the La Sal Mountain adds so much to the beds trangressed; and a still higher series of sandstones and conglomerates is known, so that, altogether, it is estimated that not less than 1,500

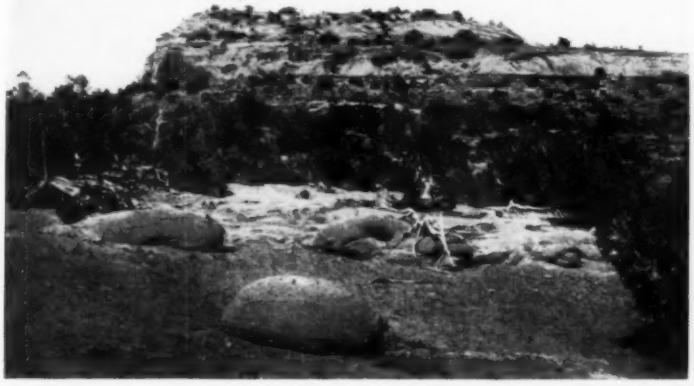

FIG. 6.—The lowest strata of the La Plata sandstone, north side of Cañon Colorado near its head. Shows the characteristic cross-bedding and cavernous weathering. Nodular masses on level floor of foreground belong to upper beds of Vermilion Cliff (Dolores) sandstone (p. 646).

and possibly 2,000 feet of Permian (?) or upper unfossiliferous Pennsylvanian beds have been eroded in the locality of the section first mentioned, opposite Moab.

On West Creek, the western stream from Unaweep Canyon, the "saurian conglomerate" is seen overlapping from the heavy conglomerates of the Permian (?) to the granite-gneiss-schist complex of Uncompahgre Plateau. This is the overlap represented on the Hayden Map of western Colorado, and interpreted by Peale as a part of the overlap of all formations from the upper Carboniferous to the

Dakota about an island of ancient rocks which he believed to have never been completely submerged until the Dakota epoch (**29**). This view is manifestly not wholly correct, in that it does not recognize the extent of the denudation of the intervals preceding and following the Dolores epoch. Only the latter of these was known to Peale. As for the uppermost Paleozoic beds of West Creek there is evidence (presented on p. 662) that they do there abut against the granite of a continental mass, as noted by Peale. The point of interest here is that the Dolores conglomerate has no such boundary and was probably deposited on the granites, gneisses, etc., over the whole area of the Uncompahgre Plateau, its absence in any given locality being satisfactorily explained by the pre-La Plata erosion.

From the facts presented, it would seem established that the Dolores formation is represented in the Grand River Valley by the Vermilion Cliff sandstone, together with about 100 feet of thin-bedded sandstones, shales, and limestone conglomerate below it.

Relation of the Dolores conglomerate to the Shinarump conglomerate.—The discovery of the "saurian conglomerate" and the unconformity below it makes it necessary to trace that horizon with care through the Plateau province. There seems to be no suggestion of such a conglomerate in the statements of any writer on the geology of the region, except Newberry. In his "General Section of the Valley of the Colorado" (**28**, p. 99) there is a member, 92 feet in thickness, described as, "Greenish gray micaceous conglomerate and gray sandstone, separated by red and purple shales." This occurs below 350 feet of red sandstone which I correlate with the Vermilion Cliff sandstone, and there is evidently a general correspondence to the 104 feet of strata below the Vermilion Cliff west of Moab. As Newberry measured this member of his section only a few miles below Moab it seems almost necessary to assume that the 92 feet of strata here referred to belong to the lower part of the Dolores, and include the fossiliferous conglomerate. Between this conglomerate and fossiliferous Pennsylvanian limestone Newberry found 514 feet of sandstone described as liver-colored, brick red, or white, with shale partings. Clearly the gypsiferous series of Fisher Creek, the overlying conglomerates and sandstones, and a considerable part of the underlying Permian (?) beds are absent on the line of Newberry's

section, implying a stratigraphic break comparable to that we found, and the probable horizon of the break is below the conglomerate.

The question as to the correlation of the Dolores formation with some portion of the Plateau section generally assigned to the

FIG. 7.—Near head of Cañon Colorado, Utah. Shows massive Vermilion Cliff (Dolores) Triassic sandstone, thinner sandstones above, and, in knoll on left hand, the lowest sandstones of the La Plata Jurassic.

Trias becomes mainly a study of what has been called the "Shinarump Group" by Powell and particularly of the relatively thin bed called the "Shinarump conglomerate." I have made such a study and

embodied the result in a paper which will appear in this journal during the current year. A brief summary of certain facts and conclusions will suffice in this place.

The Shinarump conglomerate, named by Powell (**31**), is in the midst of a series of strata well shown to the north of the Grand Canyon called the Shinarump Group by Powell (**33**), who believed the whole to be Triassic. Gilbert (**14**), Walcott (**37** and **38**), and Dutton (**9**) have observed unconformity by erosion below the conglomerate, while Walcott obtained Permian fossils in the lower part of the group in the typical Kanab section, and since that discovery geologists generally have adopted Walcott's view that the Shinarump conglomerate should be taken as the base of the Trias of the Plateau Province.

The correspondence in stratigraphic position between the Shinarump and the lower conglomerate of the Dolores formation naturally suggests their identity and I am strongly inclined to believe that they will ultimately be found to occur at the same horizon. There are, however, some discrepancies and apparent differences between the observed sections that must be explained before this opinion can be accepted.

It has been asserted by Powell and Dutton in almost unqualified terms that the Shinarump group extends from the Grand Canyon district to the Uinta Mountains, and Dutton has named the junction of the Grand and Green rivers as a locality where the whole group is present in typical development (**9**, p. 144) and where the conglomerate bed exhibits the same characters as in the Shinarump Cliff of southern Utah (**10**, p. 208). Both assertions seem to have been based on insufficient knowledge of the section below the Vermilion Cliff sandstone, for no descriptive data appear in the reports of these geologists to substantiate the claim. As far as I can ascertain, no geologist except Powell has examined the section near the confluence of the Grand and Green Rivers and he gives in his reports only general statements concerning the strata between the Vermilion Cliff sandstone and the Carboniferous beds referred to the Aubrey.

In the vicinity of the Henry Mountains Gilbert reports (**14**) a stratum correlated by him with the Shinarump conglomerate at 350 feet below the Vermilion Cliff sandstone, and some miles southeast of the Henry Mountains at Clay Hill divide, H. S. Gane found (**7**)

a Triassic crocodile, *Heterodontosuchus ganei* Lucas (**24**) with fossil wood in limestone conglomerate near the base of the Dolores formation. Gane was familiar with this formation and traced it to Clay Hill from southwestern Colorado. The beds are apparently continuous westward to Glen Canyon of the Colorado about 20 miles. This observation of Gane is most important as bringing what I think can be unhesitatingly considered to be the fossiliferous zone of the Dolores formation into the heart of the Plateau country. Actual

FIG. 8.—View in canyon of Grand River about 12 miles above ferry at Moab, Utah. Looking west across river; to show angular unconformity at base of Dolores Triassic beds. Cliffs of columnar rock are formed of Vermilion Cliff sandstone. Beds beneath unconformity are considered to belong to Permian (?).

demonstration of the relation of the Clay Hill fossil-bearing conglomerate to the Shinarump conglomerate is yet to be furnished.

One can scarcely question that Powell, Dutton, Walcott, and others have applied the name Shinarump conglomerate to a single bed or formation commonly less than 100 feet thick, as far as the country west of the Colorado is concerned, from the mouth of Paria Creek to the vicinity of St. George, Utah. No fossils have been found

in it and it has not been described in detail as to the character, size, and abundance of the pebbles. But from the mouth of Paria River southeast, below the Echo Cliffs, which are mainly formed of the Vermilion Cliff sandstone, the Shinarump conglomerate has unfortunately not been absolutely traced, so that its relation to the vertebrate-bearing beds found by Ward in the Little Colorado Valley is uncertain. The vertebrate fauna obtained by Ward and Brown (**39**, **40**) from several localities near the Little Colorado from the midst of the strata, rich in fossil wood, is clearly the same as, or similar to, that so widely known in the Dolores formation, the most common form being the crocodile of which the type was found by Gane in the Dolores at Clay Hill. Ward does not identify the Shinarump conglomerate as a single marked bed, but applied the term to 800 feet of strata entirely below the vertebrate-bearing horizon (**40**). Dutton, on the other hand, has thought to recognize the Shinarump conglomerate in typical development as far east as the Zuni Plateau in New Mexico (**11**).

At the present time, it seems to me not improbable that the horizon of the original Shinarump conglomerate of the Shinarump Cliffs is near, if not equivalent to, the vertebrate-bearing strata of the Little Colorado Valley, being there perhaps less conspicuously conglomeratic than in the type locality. The "conglomerate" is usually described by Dutton and others as really a coarse sandstone with pebbles irregularly scattered through it. Dutton ascribes a fluviatile origin to it, and such is also clearly the mode of formation of the Dolores conglomerates, which vary greatly in character in different places. It is surely not unlikely that beds of this character, but of different horizon, have been mistaken for the same by reconnaissance observers at widely separated points. This might be suspected from the character of the so-called conglomerate alone, and is rendered quite plausible by Ward, who found sandstones containing some pebbles variably developed in different sections through some 800 feet of strata (**40**).

The occurrence of a vertebrate fauna of upper Triassic age over a wide expanse of country, in Arizona, Utah, Wyoming, Colorado, New Mexico, and probably also in Texas, seems the most definite fact from which to start in studying the problem of the western Trias.

CARBONIFEROUS FORMATIONS

Sedimentary formations of the Carboniferous System are but sparingly exposed in the eastern part of the Plateau country, erosion having penetrated to them in only a few places. They were found by

FIG. 9.—View in Grand River Canyon at mouth of Castle Creek, Utah. Shows characteristic scarp of Vermilion Cliff sandstone. Probably about 100 feet of thin-bedded strata below belong to Triassic and remainder to Permian (?), the unconformity between them not being exhibited.

Peale in the valleys of Grand and Dolores Rivers and in Paradox and Sindbad Valleys. While the Triassic and other Mesozoic rocks of the Plateau district can be traced continuously to the mountains of Colorado, the correlation of the Paleozoic formations depends entirely

upon stratigraphic position in different areas and on inherent characters.

In the area under discussion, Peale distinguished an unfossiliferous series of red beds lying below the Trias, and a fossiliferous series of still lower horizon. The former he mapped as "Upper Carboniferous," though often referring to it, in his reports, as possibly Permian, and the latter was referred to the "Middle Carboniferous." During our reconnaissance various observations were made touching the character and relations of both these series.

THE PERMIAN (?) RED BEDS

On Sheet XIV of the Hayden *Atlas of Colorado*, Peale represents "Upper Carboniferous" beds abutting against granite on West Creek near Dolores River, and thence extending westerly to the canyon of Grand River in Utah. The same formation is shown in Paradox and Sindbad Valleys. While the general distribution of the pre-Triassic red beds is no doubt fairly represented on the Hayden map, Peale was unable to make sufficiently detailed study of the formation to correlate the various partial sections examined. Our observations were also far too incomplete to permit of a satisfactory description of the whole section. This is the more difficult because of a gradual change in the character of the formation as distance from its eastern border increases.

It was observed by Peale that the "Upper Carboniferous" beds near the granite on West Creek were conglomerates rich in granite, "proving that during their deposition there was adjacent land of which the rocks were granite" (**29**, p. 56). He also represents a shore-line near this locality, in profile sections across the Uncompahgre Plateau (**29**, Plate IV). Owing to "a steep dip" of the conglomerates away from the granite Peale does not place the shore-line immediately at the contact seen crossing West Creek; but, as no "Middle Carboniferous" strata are present adjoining the granite the boundary does in fact represent correctly the overlap.

That the strata in the vicinity of the granite do dip westward at angles of 15° or more is true, but in a ravine on the south side of West Creek and about ½ mile from it, I observed grits to rest directly on granite with a westerly dip of 12° to 15°, exhibited in strata near

the base. No fault was found, and it seems to me improbable that the boundary is of that nature in the vicinity of West Creek. Where the sediment was seen resting on granite, the lower layers consisted

FIG. 10.—In a ravine on south side of West Creek, Colorado, about 5 miles east of Dolores River. To show character of Permian (?) conglomerates and grits very near granite mass of Uncompahgre Plateau from which they were derived (p. 662).

of coarse, angular gravel, scarcely bedded at all. At a distance of a few feet above the granite bedding planes become more distinct, through alternation of finer and coarser material aided by color differ-

ences, the finer-grained material being reddish. At 25 feet above the granite the characteristic alternation of grit and conglomerate began. But the distribution of pebbles and bowlders is very irregular, the latter are often subangular, and the whole is so little consolidated that the disintegrated beds seem like surface gravels. Fig. 10 shows the appearance of the beds in the ravine in question. It is but a few hundred feet from this point to the contact which was seen.

FIG. 11.—Looking southward across West Creek, Colorado, near mouth. Canyon of Dolores River faintly outlined on right. The upper cliffs of view are caused by massive La Plata sandstone (Jurassic). Next lower cliffs and headlands on right are formed of Dolores or Vermilion Cliff Triassic sandstone. Below latter, section is that discussed on p. 667, and referred to Cutler Permian (?).

Similar coarse conglomerates occur along the road on the north side of West Creek, seeming there like partially consolidated stream gravels, but examination shows them interbedded with finer grits of the series.

At about 3 miles west of the granite line on the south side of West Creek, Mr. Woolsey measured the following section of sub-Triassic strata, the locality being below the central point seen in Fig. 11.

SECTION ON SOUTH SIDE OF WEST CREEK (L. H. WOOLSEY)

		FEET
	Top. Triassic red beds.	
20.	Conglomeratic grit, fine-grained, pinkish	50
19.	Interval, mainly covered by talus, but with pinkish grit revealed here and there	140
18.	Interbedded arkose and shale grading upward into shale	8
17.	Conglomerate, containing pebbles 4–5 inches in diameter, of various granites, in matrix of red arkose sand	2
16.	Covered interval	30
15.	Friable grits not well exposed and probably very similar to No. 14	80
14.	Conglomerate and fine arkose, interbedded, the pebbles generally of coarse granite and gneiss, up to 12 inches in diameter	35
13.	Covered by talus	75
12.	Arkose, red, fine-grained, with occasional pebbles of granite or greenstone, 3 inches diameter	42
11.	Concealed by talus	13
10.	Conglomerate of gneiss and coarse granite; bowlders up to 12 inches diameter; arkose matrix	5
9.	Concealed by débris, but apparently like	20
8.	Conglomerate arkose, alternating fine and coarse; the finer-grained parts are similar to No. 7; the conglomerate carrying bowlders of various granites up to 6 inches diameter	30
7.	Arkose, reddish, mostly fine-grained with pebbles 1 inch or less in diameter; occasional bowlders of different granites to 9 inches; toward top becomes interbedded with thin red shale layers, but lenses of bowlders are also present in this upper part	135
6.	Conglomerate, coarse, the granite and gneiss bowlders reaching 1½ feet in diameter, the largest ones near top, rests unconformably on 5	5
5.	Arkose grit and red shale alternating; 4 feet of fine-grained arkose at base, with thin seams of shale; these become more and more prominent toward top; coarse lenses of conglomerate at several horizons; isolated bowlders occur in certain shale layers	15
4.	Arkose grit, reddish, grading into coarse conglomerate at top, containing some bowlders 1½ feet in diameter	10
3.	Shale, red and green, irregular in thickness, owing to erosion	2
2.	Arkose grit, dark reddish, conglomeratic and seldom cross-bedded, the coarser parts in lenticular bodies; granite pebbles reach 6 inches diameter; a few pebbles of greenstone, the great majority being granite or gneiss	32
1.	Grit-conglomerate, gray, pink, or purplish, in massive cross-bedded banks, with numerous layers of fine grain, and usually darker color	150
	Total	879

The pebbles of the conglomerate strata of this section are principally of granite and the most abundant variety is the very coarse-textured one with large orthoclase crystals occurring in the nearest exposures of the Uncompaghre Plateau. Among the pebbles are some of greenstone schist which indicate that the pre-Cambrian complex furnishing this material is similar to that from which the Cutler conglomerate of the San Juan was derived. Similar greenstones were observed in the conglomerates of Grand River Valley.

Below the measured section there may be several hundred feet of similar strata, for the somewhat deeper cutting of Dolores River does not reveal the base of the succession of grits and conglomerates. The next lower formation is probably a series of gypsiferous shales and sandstones and the nearest locality at which such strata are known to occur is in Sindbad Valley, 12 miles south from West Creek. A fault running near the base of the northeastern scarp prevents a clear determination of the relations but the gypsiferous beds are manifestly older than the strata below the Dolores. These belong no doubt in the series measured on West Creek. Owing to complex folding and faulting to be discussed on another page, the extent and relations of the gypsum-bearing beds cannot be ascertained, but they are apparently some hundreds of feet in thickness.

That the gypsiferous section occurs between two series of sandstones, shales, and conglomerates, is indicated by the observations on Grand River (p. 654). In discussing the unconformity at the base of the Dolores, it was stated that going northeast from Moab, up Grand River, a succession of shales, sandstones, and conglomerates appears between the fossiliferous Pennsylvanian beds and the Dolores. The structure brought out in Fig. 8 shows that the intermediate beds rest on the Pennsylvanian.

At the time we traversed Grand River Valley, we did not know of the existence of the gypsiferous beds in that region, but on the way to the northern stope of the La Sal Mountains in the valley of Fisher Creek a considerable thickness of such strata was found. As in Sindbad Valley, a zone of faulting and folding interferes with an accurate determination of relationship on the line of travel.

No doubt the detailed nature of the section between the Pennsylvanian and Triassic can be fully determined in Grand River Canyon,

and without difficulty. A few miles above the point at which we left Grand River, Boutwell found a section of "light pinkish-purple, shaly sandstones which include coarse cross-bedded sandstones and conglomerates with well-rounded granite and porphyry pebbles" under a massive sandstone which corresponds to the Vermilion Cliff (1). These might belong to the section resting on the Pennsylvanian beds near Moab, but seem much more probably to represent strata above the gypsiferous beds and roughly equivalent to those seen on West Creek.

Comparing the strata known on Grand River between the Dolores base and the Pennsylvanian limestones with the Cutler formation (Permian?) of the San Juan Mountains it is clear that the gypsiferous part of the series has no similar representative in the mountain district. If such beds ever existed in the San Juan region, they were removed prior to the deposition of the saurian conglomerate, and this does not seem at all unlikely, for gypsiferous beds are known in the Paleozoic red beds of northwestern Colorado, as reported by Peale (29).

The grits and conglomerates of West Creek are so near their source that they differ from the Cutler beds in being much coarser and more strongly arkose, but the section seen on Grand River and Fisher Creek certainly resembles in lithologic character the Cutler beds of the Uncompahgre Valley below Ouray, and appears to occupy the same stratigraphic position.

The Cutler formation and the pre-Dolores red-bed strata of Grand River clearly correspond to the lower part of Powell's Shinarump Group, that is, to the "Permo-Carboniferous" of the Wasatch and Uinta Mountains, according to the nomenclature of the Fortieth Parallel Survey, or to the Permian of Dutton, in the Grand Canyon monograph. Fossils indicating a Permian or Permo-Pennsylvanian age were found by the Fortieth Parallel geologists in the Wasatch Mountains and by Walcott in the Kanab Valley of northern Arizona. The apparent absence of fossils in most localities where these beds have been examined is no doubt due to the fact that they are mainly continental deposits, an origin indicated by their texture.

The site of one of the land masses from which these deposits were derived is shown by the relations existing on West Creek. Peale assumed that this plateau belonged to an island extending eastward

through the area now traversed by the Gunnison Canyon, where Mesozoic beds rest on the pre-Cambrian complex. This may be true, but it must be borne in mind that the pre-Dolores and pre-La Plata uplifts with their succeeding denudations may have removed the entire Paleozoic section from much of this tract.

As distance from the mountain source of these clastic materials increases, the beds are naturally finer grained and grade into shales and marls, and correlation of widely separated sections becomes difficult. It is evident that the sub-Dolores and probably Paleozoic red beds need much closer study as to their structural relations to the overlying Triassic, as well as careful record of sections at favorable points, before correlation can be made satisfactory.

PENNSYLVANIAN SERIES

Fossiliferous Carboniferous strata were found by Newberry in 1859 in Grand River Canyon and in the lower part of Cañon Colorado. The section referred by him to the Carboniferous was described as follows in the "General Section of the Valley of the Colorado" (**28**, p, 99).

		FEET
14.	Blue limestone, somewhat cherty. Fossils: *Spirifer cameratus, Athyris subtilita, Productus semi-reticulatus*	110
15.	Bluish-white, red, or mottled sandy limestone, with partings of red shale	95
16.	Hard, blue cherty limestone. Fossils same as No. 14	36
17.	Alternations of blue limestone, red and gray sandstone, to bottom of cañon	1,000

On the map accompanying Newberry's report the point at which he reached Grand River is located only about 6 miles above the junc tion with Green River, whereas according to the La Sal sheet of the U. S. Geological Survey, Cañon Colorado, the name of the side gorge descended by Newberry, joins Grand River Canyon at 9 miles below Moab and 24 miles above the union with Green River. Whether Newberry's locality be near the junction of the Grand and the Green, or but a few miles below Moab, it is natural to assume that a fossiliferous Pennsylvanian Carboniferous section discovered by us on the northwest side of Grand River, opposite Moab, is identical stratigraphically with some part of that found by Newberry. The faunal

evidence, however, makes this conclusion more or less open to question, as will appear from the ensuing discussion.

At about three fourths of a mile northwest of Grand River and on the southwest side of the valley traversed by the stage road from Moab to Thompson station on the Rio Grande Western Railroad, there is an excellent section of the strata for several hundred feet below the Vermilion Cliff sandstone. The beds dip gently to the southwest, and it is believed that no fault crosses the line of the section, although its base is immediately adjacent to the southwestern fault of a zone traversing Spanish Valley. The following section, including some of the Triassic beds, was measured by W. H. Emmons and L. H. Woolsey.

SECTION NEAR GRAND RIVER, OPPOSITE MOAB, UTAH

		FEET
	Top	
32.	Sandstone, massive or shaly, dark red at base and bright red at top	20
31.	Shaly, conglomeratic sandstone, reddish limestone pebbles, the size of a pea or smaller, with few bone fragments	6
	Dolores Triassic	
30.	Sandy shale, red and green	5
29.	Débris slope, of red shale fragments	20
28.	Limestone conglomerate, with a few inches of limestone at top, fossil, wood, and bone fragments; pebbles less than 2 inches diameter	10
27.	Sandstone, gray, massive	20
26.	Limestone conglomerate grading into sandstone	1½
25.	Sandstone, gray, massive becoming shaly near top	23
24.	Calcareous sandstone and fine-grained conglomerate, mainly sandy, with conglomerate near base and top. Pebbles of limestone and sandstone with occasional bone fragments; pebbles vary from size of peas to several inches	9
	Permian (?)	
23.	Red sandy shales, alternating with sandstone	8
22.	Conglomerate, containing pebbles of limestone and sandstone	·1
21.	Sandstone and shale alternating, red and green, the shales sandy and friable	35
	Hermosa Pennsylvanian	
20.	Blue limestone, weathering dirty buff; near top a layer contains pipe coral	10
19.	Sandstone, thin bedded, some crumbling, some massive, red or gray	40
18.	Gnarly looking bluish limestone, sandy	3
17.	Sandstone, pink to gray, massive, friable	23

16.	Sandstone and limestone in alternating thin layers, crumbling	25
15.	Limestone, blue, weathering buff; crinoid stems near base, corals above	40
14.	Sandstone, light red, fine-grained, cross-bedded	30
13.	Sandstone, gray, massive, calcareous	5
12.	Sandstone and shale with a few thin limestone layers; nodular forms of weathering common	60
11.	Limestone, blue, gnarly looking, massive	1½
10.	Sandstone red and green layers alternating	12
9.	Sandstone, red, micaceous, alternating with sandy shales	60
8.	Limestone, sandy near base, gnarly, fossiliferous	6
7.	Shale and sandstone, red	10
6.	Sandstone, red	8
5.	Shales, purplish, sandy micaceous, very thin-bedded	4
4.	Limestone, bluish, in hard dense beds, 1 to 2 feet thick, fossiliferous	6
3.	Sandstones, thin-bedded, alternating with purplish sandy shales; sandstone layers less than 3 feet thick	15
2.	Sandstone, bluish-gray, friable, micaceous, cross-bedded	7
1.	Sandstone, gray, green, or purplish red	15
		539

Above this section comes a cliff of red, pink, and gray sandstones apparently embracing the Vermilion Cliff sandstone and possibly a part of the White Cliff sandstone, not examined in detail. No lower beds are exposed in the valley.

The upper 104½ feet of the section represents the fossiliferous Triassic beds immediately below the Vermilion Cliff sandstone which is here well developed. The next 44 feet of beds is provisionally referred to the Permian, and in that case represents the basal portion of that series. It may possibly belong with the underlying Pennsylvanian Series, or partly to the overlying Triassic, if the conglomerate, No. 22 of the section, be taken as the base of that series.

From the limestones of the Pennsylvanian portion of the section, Nos. 1 to 20, inclusive, we obtained the fossils shown by column IV of the table on p. 672. Probably no other exposure near near Moab reveals so great a thickness of the Pennsylvanian strata as that we examined, but doubtless the upper fossil-bearing limestones may be found in Spanish Valley. It is not known whether they are continuously exposed in the canyon of Grand River from Moab to the mouth of Cañon Colorado. The southwesterly dip of the Spanish

Valley anticline brings the Triassic beds to the river level at a short distance below Moab.

Another collection of fossils was made in 1901 by Mr. L. M. Prindle, on the road about half a mile northwest of the locality we studied, from strata visibly belonging to the section given. By Mr. Prindle's courtesy, I am permitted to indicate the forms identified by Mr. Girty in his collection, in column III of the table.

The only other locality where we observed fossiliferous Pennsylvanian beds is on the southwestern side of Sindbad Valley at the same point where Peale found bluish limestone carrying Producti, Crinoid, and Corals. The specimens collected by him were abandoned during an attack by Indians, so that the definite character of this fauna was not determined. In his report, Peale gives a section (**29**, p.71) in which the fossil-bearing strata are placed beneath shaly sandstones having an estimated thickness of 3,500 feet, and above these are the gypsiferous strata of the valley floor. The fault zone parallel to the axis of the valley is more complex than Peale supposed, and it seems probable that the fossil-bearing strata form a narrow and vertically upturned block thrust up almost to the level of the Vermilion Cliff sandstone, and that no continuous section exists in the valley by which the position of these fossiliferous beds in the whole section can be established. They are bounded by a fault on the northeast, as well as on the southwest. These fossil-bearing beds were also examined by Mr. A. C. Spencer in 1899, and a collection of fossils was made.

From the bluish limestone ledges of Sindbad Valley the fossils indicated in column V of the table, p. 672, were obtained, either by Mr. Spencer or by our party.

In view of the meager statements of Powell and Newberry as to the sections examined by them, and the isolation of the Moab and Sindbad Valley occurrences, the most satisfactory basis for a correlation of these Pennsylvanian sections lies in comparing the fossils collected at the several localities. Through the kind assistance of Mr. G. H. Girty, who has examined all the material except the collection by Newberry, I am able to present in tabular form the lists of all known fossils from the localities named. For comparison the known occurrence of the species of the lists in the Hermosa forma-

tion, or in probable equivalents of that formation in central Colorado, is also indicated.

TABLE OF CARBONIFEROUS FOSSILS FROM UTAH AND COLORADO

	I	II	III	IV	V	VI
Syringopora multattenuata				×		
Syringopora sp.			×			
Lophophyllum profundum				?	×	×
Zaphrentis sp.				×		?
Campophyllum torquium			×	×		×
Axophyllum rude				×		
Eupachycrinus platybasis*	×					
Erisocrinus typus	×					
Ceriocrinus inflexus	×					
Echinocrinus cratis	×					CB
Echinocrinus trudifer ?			×			L
Echinocrinus Dinnini ?			×			
Echinocrinus sp.					×	
Fenestella aff. tenax			×			×
Fenestella sp			×			×
Polypora sp.			×	×	×	?
Goniocladia sp.*	×					
Fistulipora sp.			×	×		?
Rhombopora lepidodendroides			×			×
Lingulidiscina sp.					×	
Derbya crassa ?		×*	×	×		?
Derbya aff. robusta	×					
Meekella striaticostata	×					×
Orthotichia Schuchertensis					×	
Enteletes hemiplicatus					×	
Chonetes granulifer	×				×	
Productus semireticulatus	×	×			?	?
Productus semireticulatus var.	×					
Productus Portlockianus					×	
Productus punctatus	×	×	×	×	×	×
Productus Nebraskensis	×	×†	×	×	×	×
Productus aff. Humboldti*	×					
Productus aff. porrectus*	×					
Productus scabriculus*		×				
Productus cora	×			×		×
Productus nodosus*		×				
Productus multistriatus*	×					
Productus subhorridus*	×					
Marginifera Lasallensis				×		CB ?
Marginifera Wabashensis ?	×			×		?
Marginifera ? sp.	×					
Spirifer cameratus	?	×		×	×	×
Spirifer Rockymontanus	×					×
Squamularia perplexa				×		×
Spiriferina Kentuckyensis	×					×
Composita subtilita	×	×		×	×	×
Hustedia Meormoni				×		CB
Puguax sp.				×		CB ?
Drelasma bovidens				×		CB
Deltopecten Van-vleeti			×			

* Orthisina umbraculum of Newberry. † P. Rogersi of Newberry.

TABLE OF CARBONIFEROUS FOSSILS FROM UTAH AND COLORADO—*Continued*

	I	II	III	IV	V	VI
Myalina Kansasensis			?		×	
Myalina ampla		×				
Myalina subquadrata	u§					?
Myalina Apachesi*	u					
Myalina Wyomingensis ?	u					L ?
Edmondia subtruncata	×					×
Edmondia Mortonensis ?					×	
Allerisma terminale	×	×‡	×			×
Choenomya Leavenworthensis					×	×
Schizodus Wheeleri	×					
Schizodus sp	×					?
Pleurophorus sp	×					
Bellerophon majusculus*	×					
Bellerophon sp	×	×				?
Bellerophon percarinatus					×	?
Patellostium aff. Montfortianum	u					?
Euconispira excelsa*	×	×				
Euconispira sp					×	?
Worthenia tabulata ?					×	
Euomphalus catilloides	×			×	×	×
Euomphalus sp	×					
Naticopsis remex	×					
Naticopsis Altonensis ?					×	?
Naticopsis monilifera				×	×	×

* Orthisina umbraculum of Newberry.
† P. Rogersi of Newberry. ‡ A. Subcuneatum of Newberry.
§ Species designated by White as from the "Upper Aubrey" are marked "u."

I. Confluence of Grand and Green Rivers, Utah; collected by Powell expedition, determined by C. A. White (**32**, pp. 88–92).

II. In or near Canyon of Grand River, below Moab; collected by J. S. Newberry, 1859 (**27**, p. 98).

III. On road about 4 miles northwest of Moab, Utah; collected by L. M. Prindle, 1901.

IV. Cliff about 3½ miles northwest of Moab, Utah; collected by Cross party, 1905.

V. Sindbad Valley, on Colorado-Utah line; collected by A. C. Spencer, 1899, or Cross party, 1905.

VI. Occurrence of species of this table in the Hermosa formation of southwestern Colorado, indicated by species not yet found in the Hermosa formation but known from the Crested Butte quadrangle, Colorado, or the Leadville district, are also indicated, by CB or L respectively.

Concerning the faunal relations indicated by this table, Mr. Girty has kindly given me the following comments for publications:

Powell's collection at the junction of the Grand and Green Rivers shows a fauna probably equivalent to that of the Aubrey formation. Many of the charac-

teristic Aubrey forms are, however, lacking (*Productus occidentalis, P. Ivesi, Allerisma capax*, etc.). This fauna is more like that of the Weber quartzite formation of Bingham, Utah, which, at the present time, I provisionally correlate with the Aubrey. Newberry's list making the necessary synonymic changes is almost identical with Powell's, as far as it goes. The collection is smaller, and, of course, lacks many forms which might be obtained on further search. Considering the Powell and Newberry collections together, it is notable that they contain a considerable number of species which may be called distinctive western types, as compared with the Pennsylvanian fauna of Colorado and of the Mississippi Valley. These species are marked by an asterisk following the names in the list. In some cases nothing at all closely related to the types indicated is known from the region to the east. In other instances there are more or less similar species known which are not yet regarded as identical with western forms, although they may prove to be so.

The collections from Moab consist entirely of typical Pennsylvanian species, lacking the forms specified as characteristic of the far western areas. The distinctly Pennsylvanian forms found at the junction of the Green and the Grand occur, however, at Moab. The Sindbad Valley fauna is very closely related to that from Moab.

In view of the fact that none of these collections can be considered as exhaustive for the localities, numerical comparisons are more or less untrustworthy; yet the table brings out certain contrasts or resemblances which seem worthy of note. Out of 42 species represented in the Powell and Newberry collections but 9 have been found at Moab, or in Sindbad Valley, while out of 43 species obtained in these latter localities 29 are known from the Pennsylvanian rocks of southwestern or central Colorado.

On the basis of the fossil evidence alone there can be no hesitation in considering the Moab and Sindbad Valley sections as belonging to the Hermosa formation rather than to the Aubrey, as represented in the lower Grand River Valley.

The strong similarity which Mr. Girty has pointed out between known faunas of the Moab district and of Sindbad Valley to that of the Hermosa formation of Colorado, and the contrast with the faunas collected by Newberry and Powell, require some explanation.

As stated on p. 668 the collection made by Newberry was obtained less than 10 miles below Moab, if the Cañon Colorado of recent maps is the same as the canyon of that name through which Newberry descended to Grand River. If he reached Grand River as near to the junction of the Green as he himself supposed, the locality of Newberry's collection was still in all probability not more than 25 miles from Moab. One explanation of the difference between the Moab

collections and those of the lower Grand River lies in the assumption of insufficiency of collections at Moab, which by chance failed to include a large number of the species of the Powell collection. In view of the fact that the collections from Moab and Sindbad Valley were made by several different collectors at different times, this explanation seems hardly a plausible one. Another interpretation is that there may be a stratigraphic break, due to uplift and erosion, through which the Aubrey strata found by Powell and Newberry have been removed at Moab, in the Sindbad Valley, and to the mountain region to the east. This implies that the Hermosa beds of Moab are present beneath the section examined by Powell and Newberry. Such a break must occur at the base of the Paleozoic "Red Beds," and no suggestion of such a hiatus has come from observations in Colorado; but it is to be remembered in this connection that in southern Utah and northern Arizona, Powell, Gilbert, Dutton, Walcott, and others have noted a persistent unconformity by erosion between the Aubrey and the succeeding strata now commonly referred to the Permian through Walcott's discovery of fossils in the Kanab Valley (**37**). All of the above-named geologists have observed a conglomerate more or less widely distributed at the base of the Permian series, composed in large part of pebbles derived from the Aubrey rocks, as shown by fossils contained in them. It is, of course, possible that the denudation at this horizon may have been much more extensive than the observations thus far reported would suggest. The situation is really not very different from that concerning the unconformity and stratigraphic break now known below the Dolores Triassic formation, which a few years ago was supposed to consist in comparatively slight unconformity by erosion.

The foregoing suggestion is in some degree confirmed by the fact, determined in the Colorado region, that the Hermosa fauna is succeeded by one having a distinct, and apparently a younger, facies (**16**, pp. 245–56), that of the Rico formation, which has not been found at Moab. Mr. Girty informs me that recent data tend to correlate Rico with the Aubrey formation (in part) through the Manzano group of New Mexico. In its lithologic, stratigraphic, and faunal relations the Rico is said to be suggestive of the Manzano group, which

in turn can be correlated with the Aubrey. The Manzano fauna comprises a certain number of species which occur also in the Rico, together with others not yet found in the Rico, which are more or less characteristic of the Aubrey.[1] There is also some confirmation of the relations thus suggested in the fact brought to my attention by Mr. Girty that the Hermosa fauna bears a noteworthy resemblance to that of the upper part of the Red Wall limestone of the Grand Canyon, while markedly different from that of the Aubrey. No great emphasis can be laid upon this at present, however, since the collections upon which Meeks' list of Red Wall forms given to Gilbert (**14**, p. 178) have been lost and further study of the Red Wall fauna is necessary to elucidate this matter. There is clearly a field requiring much further investigation as to the relations of the Red Wall, Aubrey, Hermosa, and Rico faunas.

THE PRE-CAMBRIAN COMPLEX

The ancient rocks of the Uncompahgre Plateau were described by Peale as in the main granites and gneisses with a subordinate amount of various schists. He called them Archean, considered them to be derived by metamorphism from sediments, and correlated them with the complex so well exposed in the Canyon of Gunnison River to the east (**29**).

There is every reason to suppose that the rocks in question do belong to the same great pre-Cambrian complex which is well known in other parts of Colorado. Our limited observations in Unaweep and West Creek Canyons and at other points indicate that the old rocks of the Uncompahgre Plateau are comparable in most elements with those of the Needle Mountains and the Gunnison Canyon. There are many gneisses and schists, the origin of which is not wholly evident. Some gneisses are granitic in composition and may plausibly be considered as mashed or sheared granite. But there are many very dark hornblendic schists and others containing both hornblende and biotite. Such gneisses and schists are probably the oldest rocks of the district and are naturally referable to the Archean.

The gneissoid and schistose rocks are cut by many bodies of coarse

[1] The relations of the Manzano group will be discussed in a forthcoming bulletin of the Survey by W. T. Lee and G. H. Girty.

or fine-grained granite, little modified by movement or pressure, and these seem plausibly to be equivalent in age to the massive granites of the Needle Mountains, which are later than the quartzites of the Uncompahgre formation referred to the Algonkian in the Needle Mountains and Ouray folios.

That the Uncompahgre quartzites are also present in the West Creek area is indicated by two observations. In West Unaweep Canyon, near the west end, a patch of white quartzite, some hundreds of feet in visible extent occurs on the north side of the valley a few hundred yards north of the road. Mr. Kay visited this outcrop and found it to consist of quartzite of fine, even grain, for the most part, if not wholly, surrounded by granite.

Another occurrence of quartzite was discovered by Mr. Woolsey within the area of Permian (?) sediments very near the granite line on the south side of West Creek and several hundred feet above the stream. These quartzites were surrounded and in part covered by the Permian (?) grits, and they apparently form a pinnacle or knoll which has been buried and is now again exposed by erosion. Small quartzite fragments were observed in the adjacent granite.

These quartzite occurrences, of which scarcely more than notice of their existence can now be said, are very suggestive in the matter of the correlation of the extensive Uncompahgre formation of the San Juan region with the still greater series of ancient quartzites in the Uinta Mountains. Both have been referred to the Algonkian and their similarity emphasized. The quartzites of West Creek are about 90 miles from the type locality for the Uncompahgre quartzites at Ouray on the north side of the San Juan Mountains, and 150 miles from the Uinta Mountains. They are thus so nearly intermediate as to add weight to the correlation suggested.

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NOTES ON THE GEOLOGICAL SECTION OF MICHIGAN

PART I. THE PRE-ORDOVICIAN

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INTRODUCTION

It is not as easy to summarize the section of Michigan as, for instance, a compact state like Iowa. For one thing the state is so spread out that, turned around by its southeast corner on the map, it would reach beyond New York into the Atlantic Ocean, and turned around by its northwest corner, would extend to Hudson's Bay and into the Dakotas. Again it includes within its borders representatives of probably the oldest land masses, which have been frequently, if not continuously, above sea level ever since they were first elevated. The geological succession may therefore be expected to be interspersed with beds laid down on land and in lakes fresh and salt, and seas like the Caspian and Black, by stream and wind, as well as wave.

Part I includes the pre-Trenton rocks which even the drill has not reached in the Lower Peninsula.

In preparing these notes the state geologist had assistance from Professor Seaman of the College of Mines as to the older rocks to such an extent that it may be best expressed by joint authorship. Indeed what he knows of the Upper Peninsula is so interwoven with what he has learned from and with Professor Seaman that anything he could write would be essentially of that nature.

With regard to the Paleozoic series he has had the advantage of the constant assistance of Mr. W. F. Cooper, and of unpublished reports by A. W. Grabau and N. H. Winchell to examine. Since, however, he differs quite materially from Dr. Grabau, and Dr. Grabau has recently given elsewhere[1] the essential features of his interpretation, no detailed reference to these unpublished reports will

[1] *Bulletin Geological Society of America*, Vol. XVII, p. 567.

System	Series Name	Formation Name	Columnar Section	Thickness	Character of Rocks
Ordovician		St. Peter		0 to 75 ?	*Sandstone:* white, waterbearing in hollows of Calciferous dolomite, but absent often
		Calciferous		255 to 180 ?	Buff and bluish dolomites often sandy, with dolomitic white sandstones.
		Munising		200	*Sandstone;* white or light, waterbearing.
	Neo-Cambrian Saratogan (Potsdam)	Jacobsville Redstone		0 to 1500 + (4000 ?)	*Sandstone:* red and brown and striped with streaks of red clay shale, conglomeritic where it laps upon older formations.
		Hiatus		not drawn to	scale, the relation of the Freda to the Lake Superior Sandstone being uncertain, probably one formation.
	Upper Keweenawan, perhaps	Freda		(900 +) ?	*Sandstone:* red, with some felsitic and basic débris, and salt water.
	Mio-Cambrian	Nonesuch		350 to 600	*Shales:* dark, fissile beds, with dark basic fragments, and products of decomposition of lavas copper-bearing.
		Outer		1700 to 3500	*Conglomerate:* very heavy, red, with large rounded bowlders of all lower formations including jaspilitic iron ores, agate amygdules, gabbro aplites, etc.
		Copper Harbor		1800 to 400	*Traps:* basaltic lavas, and at least one—the "Middle"—conglomerate.
Cambrian or Primordial		Lake Shore		2200 to 340	*Conglomerate:* very heavy, like the outer conglomerate.
	Keweenawan	Great Eagle River		2300 to 1417	*Group* of basic lava flows, with *frequent* beds of sediment, Marvine's (c).
	Lower Keweenawan, perhaps eo-Cambrian	Ashbed		1456 to 2400 ± (50 sediment)	*Group* of basic lavas of the "ashbed" type with scoriaceous sediment and only 50 feet or so of conglomerate. Locally felsites'
		Central Mine		823 to 25000 ? (480 sediment)	*Group:* mainly of lavas of the augitic ophite type, with infrequent sediments. At the top is the "Mesnard epidote" and just beneath the heaviest flow, over 1 000 feet thick at times, known as the Greenstone. Under this is the Allouez conglomerate. Marvine's No. 15. No. 13 is the Calumet and Hecla conglomerate or lode. The Kearsarge Lode is shortly above 9.
		Bohemian Range		? to 9500 + (500 sediment)	*Group:* mainly of basic lavas, but with intrusive and effusive felsites and coarse labradorite porphyrites; also intrusive diabase dikes and gabbro and gabbro aplites.
	Animikean neo-Huronian	Michigamme		1000 to 4000	*Slates:* black and graphitic, and graywacke slates, passing into graywacke arkoses, and quartzites; metamorphosed into staurolite, chiastolite, garnet, and other mica schists and phyllites.
		Bijiki		500 to 800	*Iron formation or schist:* slates with cherty carbonate and soft ore.
		Goodrich		0 to 400 +	*Quartzite:* with conglomerate base, and above quartzite or red and green flags also volcanic material.
		Negaunee		1000 ±	*Iron formation:* cherty carbonates, altered to jaspilites, etc., with effusives and intrusives altering to hornblende schists and amphibolites.
Huronian	Mio-Huronian	Stamo		600 ±	*Slates:* graywackes and arkoses and volcanics.
		Ajibik		700 ±	*Quartzite.*
		Wewe		500 ±	*Slate:* black largely.
	Eo-Huronian	Kona		600 ±	*Dolomite:* with siliceous cherty and slaty (s histose) bands.
		Mesnard		250 ±	*Quartzite:* conglomerate and arkose, becoming a scriate schist or gneiss.
		Kewatin			
Laurentian		(Marinesean) = Laurentian		1000 +	Greenstone schists, amphibolites, hornblende schists, sericite schists or crushed felsites, rarely ellipsoidal greenstones and slates and jaspilites, very largely cut by granites, the Laurentian, and numerous other classes of injections.

be necessary. It need not be said that there are many things and many divisions in the geological column upon which further light could be thrown, and it is hoped that before long the Paleozoic geology of the Upper Peninsula may receive more careful attention. But it is the state geologist's feeling that it is well to be sure one is right before going ahead in any change of names, since any such change renders reports less readable even to the geologist, much more so to the teacher, engineer, and others who make casual use of them. This is much more the case when a number of new names are brought in at once. In regard to the scientific questions involved, see the article, "The Geologic Day," *Journal of Geology*, 1906, p. 425.

One general remark should be made. The point of view of the state geologist is largely that of a student of well records and of the drillings returned from them, in which the fossils play next to no part. Not only is the point of view of Dr. Grabau that of a paleontologist, but this must also be remembered, that the study of the paleontologist on outcrops is, in a broad and general way, the study of formations nearer their margins and more likely to be of some other type than simply marine, and if marine deposits, more likely to be deposits of the littoral, and of extreme transgression.

In studying and comparing well records it is a notable fact that certain parts of the geological column seem to be persistent and easily correlated from well to well. Others vary markedly, even in extremely short distances. These are the points where the unconformities come in.

The columnar section is divided into two parts, on different scales, since the thicknesses of the pre-Ordovician units are much greater than those of the later ones. The thicknesses in the column are those derived from wells where the formation is as flat as possible and as far removed from its source. An attempt has been made to draw the column to scale, giving each formation something like its minimum thickness when not obviously cut off by erosion, unconformity, or overlap. The numbers placed along the side, however, show also the customary range up to the greatest thickness of which we can be reasonably sure. Still greater thicknesses may and often have been estimated, but in our judgment may not have had due allowance made for faulting, initial dip, or crushing.

The Laurentian-Keewatin.—These terms we take to have the same stratigraphic meaning, since the relations are of intrusive contact—the former being applied where the areas are largely feldspathic or granitic and light colored, the other when they are mainly of basic rocks, or klastic in a good many cases, of the nature of volcanic tuff (the "Greenstone schist" or "Mareniscan"). In Michigan at least there is comparatively little if any of the commoner types of sediment and limestones, either in their altered or unaltered condition. Many of the schists which are fine grained and slaty enough to pass for altered sediments prove really to be altered felsites, or volcanic ash, or something of that kind. There is, however, a little iron-ore-bearing jaspilitic chert and rarely genuine black slates. Early conditions of erosion before there was any land vegetation would have led to the formation of arkoses and tuffs, and there may have been less ocean of a very different chemical character, accounting for the scarcity of ordinary types of sediment. Generally speaking these rocks are more or less saturated with granitic matter, either in fine-grained aplitic or coarse-grained pegmatitic veins, but the whole rock may be a gneissoid granite. These gneissoid granite bosses generally occupy anticlinal areas, and are the typical Laurentian. Around Marquette there seems to be a compound synclinal with argillites in the upper part and some ill-defined iron-bearing beds which may correspond to the Vermilion Range below, and a great deal of "Greenstone schists." These latter consist of hornblende and chlorite schist and amphibolites, including rarely "ellipsoidal greenstones," and sericite schists altered from felsites throughout, but especially in the lower parts next to the granitic anticlinal bosses. The total thickness one can estimate not less than 1,000 or more than 5,000 feet.

By Bigsby, Maclure, etc., this formation was grouped as gneiss or granite with the hornblende slate under the term primitive; by Houghton and his assistants as syenite, granite, gneiss under the term primary; by Logan as Laurentian; by Foster and Whitney as granite rocks of the Azoic period; by A. Winchell as granitic rock of the Plutonic group; by Credner as the Lower Laurentian of the Eozoic; by Brooks and Pumpelly and many others following them as Laurentian; by Rominger as Huronian; by Van Hise and the

U. S. Geological Survey as Archean (the basement and fundamental complex); by Wadsworth as the Cascade formation. Yet a glance at the various geological maps of Lake Superior shows that, however different the connotation, or meaning, and the theories of the various writers as to relationships, the areas and rocks *denoted* were mainly the same.

Of other terms the "Mona" series is referred to by Foster and Whitney (p. 35), in the European sense, similar, but probably not identical, with the sense of the term used in the *Marquette Monograph*. That and "Kitchi" are intended to be synonymous terms, but include some areas of extra highly metamorphosed Huronian.

The term Mareniscan (*Van Hise Monograph*, 19, p. 473), appears to be a later synonym of Keewatin and it was decided by the joint committee to prefer the latter, but should further discoveries make a local Michigan term needful, may be used, as Wadsworth's term Cascade is later and included, we believe, disparate things. The "Palmer gneiss" appears to be a sheared facies of some of the Huronian members up to the Siamo slate. It is only fair, however, to be ready in regard to so difficult a group as the earliest rocks, to accept a term even though there be some slight inconsistency or error made by the author, provided only that they are not so great as to destroy its usefulness by making uncertain its general application.

Huronian.—The name under which the pre-Cambrian rocks have been assembled in this state has varied. Among the earliest writers who derived their information from direct observation was Credner, then Professor Pumpelly's assistant, who published a paper in Volume II of this survey, and whose thesis for the doctorate was on *Die Gliederung der eozoischen (vorsilurischen) Formations-Gruppe Nord-Amerikas*[1], which is, as far as I know, the first original work published after that of Foster and Whitney. Douglass Houghton's "metamorphic" rocks were in the Huronian. Foster and Whitney, in spite of themselves, divided the formations to be considered, classing them all as Azoic, into granitic rocks (chap. iii); iron ores and associated rocks (chap. iv). Credner calls them all Eozoic, and divides them into Huronian and Laurentian, and the same divisions are used by Brooks and Pumpelly. As between the terms Azoic and

[1] Published at Halle, 1869.

Eozoic, Proterozoic, Archeozoic, and Archean, we are not prepared to give a final decision, but find the usage of Chamberlin and Salisbury convenient. The terms Laurentian and Huronian have been used pretty continuously in the Lake Superior region, and always with almost the same practical application, so far as this state is concerned. We think, therefore, that we should in them follow Credner and Logan. It is at present agreed to divide the Huronian into three series. A question may arise whether the lowest of these series, which is considerably older than the other two, more eroded, and quite different in distribution, may not be the Grenville or Upper Laurentian. There is, however, no local ambiguity involved, as it has always been mapped with the Huronian in this state.

Eo-Huronian.—We use this term in preference to Lower Huronian, as that was applied to the eo-Huronian and mio-Huronian until the threefold division of the "Marquette" series was recognized. The *Marquette Monograph* calls it Lower Marquette. We had always called it Mesnard (formation or series).[1] The U. S. and state survey now restrict this name to the basal member.

a) Mesnard quartzite. Well exposed on Mt. Mesnard just south of Marquette, finely ripple marked, with about 250 feet of slaty flags toward the base, which is a conglomeritic and arkose quartzite.

There are also brecciation beds, slate, quartzite, and cherty quartzite toward the Kona dolomite above.

It is at times much metamorphosed and sheared and may be confounded with underlying beds, and is at times cut by granites, but by no means as commonly as the Keewatin. We think, too, the granites cutting the Huronian have a different character, being much more inclined to a coarse porphyritic facies.

b) Kona dolomite. This is a very well marked horizon around Goose Lake, but is represented, we believe, on all the ranges and in the original Huronian, being the Randville dolomite of the Menominee Crystal Falls region, and the Bad River formation of the Gogebic Range.[2] But extensive erosion took place before the deposition of the mio-Huronian, generally removing the slates above it and often cutting deep into the dolomite.....600 ft.

[1] *1892 Report*, p. 65.

[2] Rominger's "Marble" Series, Vol. IV, p. 56.

c) Wewe slates. The slates of Goose[1] Lake, rarely left by the erosion, but exposed on Carp River, Sec. 5, T. 47 N., R. 25 W., and on Sec. 12, T. 47 N., R. 26 W., black and gray slates.....300 ft.

Mio-Huronian.—This we are inclined to believe is the main iron-bearing formation, not only of the Marquette range, but of the Menominee range as well. During this time began an epoch of basic volcanics at numerous points which continued into the neo-Huronian and expressed itself mainly in intrusives altered to amphibolite ("diorite"), chloritic schist, "paint rock," and uralite diabase in the mio-Huronian, and mainly in effusives and tuffs in the neo-Huronian.

This is Van Hise and Leith's Middle Marquette; compare also Wadsworth's "Republic" and "Negaunee" formations.[2]

a) Ajibik quartzite. Has often been confused with Mesnard quartzite. Grades upward through slaty phases into *b*).....700 ft.

b) Siamo slate. Grits, flags, and graywackes, and graywacke slates, with volcanic tuffs.....600 ft.

c) Negaunee formation. The main formation of cherty carbonates and siliceous beds with "greenalite" readily altering into jaspilitic iron-bearing formation.....1,000 ft.

Near igneous contacts it also changes into grünerite, and other amphibole-magnetite schists.

Neo-Huronian (Animikie).—The relations of this series around Port Arthur on the north side of Lake Superior and along the Gogebic range on the south are such, both as to the overlying and underlying rocks, that there can be but little doubt that they are in general coeval, and the graphitic slate horizon of the upper part seems to be widely identified. We have no hesitation in adopting the term Animikie. There may be some question as to whether it belongs in the Huronian at all. We believe Lawson considers the greatest and most profound unconformity[3] to come at the base of this formation, rather than for instance, between the Mesnard and the Keewatin or

[1] *Wewe* is Chippewa for "goose."

[2] Though he was never quite able to agree with what seems to us the proper interpretation of the stratigraphy of the same, so that the order as given on p. 66 differs so much from our views that we could hardly use it without producing confusion. See *1892 Report*, pp. 64, 66, 110, etc.

[3] The Eparchean interval.

greenstone schists, and it must not be forgotten that the Minnesota Survey has held it to be Cambrian.[1] Were the Gogebic range alone to be studied we might agree with Lawson, but there the unconformity at the base of the Animikie represents the elimination of all of the mio-Huronian and most of the eo-Huronian, thus representing a good part of Huronian time. Without question the Animikie is much less disturbed than the older formations, but we are not prepared to say that any one of the breaks before the Keweenawan is the "essential break."[2]

The divisions are:

a) Goodrich quartzite. This is represented on the Gogebic range by the Palms formation of red and green quartzose slates. But there, as on the Marquette range, there is a conglomerate base, containing pebbles of jaspilite and dolomite as well as granite. Basic tufaceous material is a sign of local volcanic activity, which continued from mio-Huronian (part of Clarksburg formation, etc.) near foci of which the formation may be very thick. Otherwise.....400 ft.

b) Bijiki formation. This is a cherty, iron-bearing member with graphitic slates, on the Gogebic range some 800 feet thick, known as the Ironwood formation and the main iron member. It was not considered in the *Marquette Monograph* so persistent as we really believe it is .....300 ft.

c) Michigamme slate. A group of black, graphitic slates and graywackes, quite wide spread—the Tyler slate of the Penokee-Gogebic range, the Lake Hanbury slates of the Menominee Range. Usually not over 1,000–2,000 feet thick. On the Gogebic range apparently..... 4,000 ft.

Keweenawan.—This term used as a technical name for a rock series is nearly synonymous with Nipigon, which has a year or so priority, but was introduced practically simultaneously in two slightly different senses; and the term Keweenawan has been so much more widely used that the joint committee agreed to retain it. Douglass Houghton included the Lower Keweenawan up to the Great Con-

[1] But Logan and Hunt in the original introduction of *Huronian—Esquisse Géologique*, p. 28—considered Huronian as Lower Cambrian of Sedgwick. But at that time, as in the earlier editions of Dana, the Potsdam was classed as Silurian.

[2] Leith in *A. I. M. E. Trans.*, 1906, p. 128.

glomerate under the general head "Trap rocks" and understood that "strictly in their chronological order" they came after the "metamorphic" slates and quartz rock. The Lake Shore traps were thought of as intrusive dikes, so that he could group the Greater and Outer Conglomerate together under the head "conglomerate" and the rest of the Keweenawan as "mixed conglomerate and sand rock." Foster and Whitney followed his divisions in their mapping, including them as the lowest divisions of the Silurian (which, as in the early editions of Dana, was understood to go down to the Azoic and include the Primordial) and as intimately associated with the Lake Superior sandstone, so much so as not to need any separate formation name. It has already been mentioned that the latter has been referred to various ages from Triassic back. Logan called them the "Upper copper-bearing" rocks; Brooks and Pumpelly the Latin equivalent "Cupriferous," and considered the formation conformable to the Huronian, but covered unconformably by the Lake Superior sandstone, and likely to be more allied to the former than the latter. Irving introduced the term Keweenaw(an), and in *Monograph V*, p. 24, recognized an unconformity (disconformity) of the Keweenawan and Huronian, as well as an unconformity above, especially with the Mississippi Valley Cambrian sandstones. Neither of the unconformities do we doubt. But they appear to be with basal Keweenawan beds disturbed by coeval volcanic activity and faulting, and seem to us quite comparable with inter-Keweenawan phenomena, while the Lake Superior sandstone and the Upper Keweenawan appear to us closely associated not merely lithologically but stratigraphically.[1] We prefer, therefore, for the present, to place the Keweenawan in the Cambrian to express that fact. If we could but be sure that there was indeed a universal cycle of sedimentation and rhythm of geological activity, by which, all the world over, crustal rearrangements and volcanic activity took place simultaneously, while at other times atmospheric conditions universally favored the deposit of limestones or black shales, there would then be more of a temptation to compare our column with the type column in Great Britain and see in the

Longmyndian red sandstone and volcanics } ..... { the correlates to the Keweenawan.

[1] See *Annual Report*, Board of Geological Survey of Michigan, 1904, p. 143.

Longmyndian flag stones and shales and Rushton schists	.....	the correlates to the Animikie black slate and graywackes.
Bradgate, Beacon Hill and Black Brook hornstones of Charnwood Forest	.....	the correlates to the Huronian cherts and jaspilites.

The Keweenawan would then indeed be pre-Cambrian. But far-off lithological correlations have too often proven a will-of-the-wisp.

Lower Keweenawan.—The conglomerates which occur at the top of the Lower Keweenawan and below the Lake Shore traps may perhaps belong stratigraphically to the Upper Keweenawan. They contain a wide variety of pebbles and large bowlders, and are in structure at times suggestive of till.

The main part of this formation cannot at its thinnest point be put down as much less than 15,000 feet. Its base in contact with the upper beds of the Animikie formation has recently (H. L. Smyth) been found north of the Gogebic range. Here its thickness appears to be near 42,500 feet, and I do not think it can possibly be reduced by any allowance for repetition by faulting and initial dip to less than 29,000 feet. Some such thickness of rock with the specific gravity of trap over against an equal thickness of granitic rocks would be needed to produce isostatic equilibrium between the bottom of Lake Superior and the Huron Mountains. Of this thickness only a small fraction is sedimentary and that of a type which may be rapidly accumulated, so that the whole series is not necessarily of great duration. The general characteristic of the lavas which made it up is that, while they run from silicious felsites and quartz porphyries to quite basic rocks, there is nothing ultra basic nor ultra alkaline known. Porphyritic crystals are mainly quartz and feldspar. These have normally crystallized earlier in the magma. A marked second generation of augite is almost unknown. When we come to estimate how much of it is sediment, however, we find that continuous diamond-drill sections would indicate for the major part of it less than 7 per cent. (5.65 per cent. in 8,500 feet, 6.65 per cent. in the 6,247 feet at Isle Royale). The greater the thickness probably the less the per centage. Making detailed allowance for the Great and certain other

heavy conglomerates at the top, we get 4,250 feet for the sediments alone—conglomerates and sandstones of very rapid deposition for the most part. A detailed section is given in the *Black River Report*, Annual for 1906, p. 400. Fairly persistent (Isle Royale, Black River, Keweenaw, Mamainse) appear to be the following divisions of the Keweenawan from below:

1. *Bohemian range group* (Irving's (1) and (2), Plate XVII) characterized by numerous flows of labradorite porphyrite type and felsites near the top and frequent intrusions, of straight-walled diabase dikes, of felsite, of gabbro and affiliated red rocks, or gabbro aplites. North of Bessemer, the thickness, igneous sills included, is .....9,500 ft. There may not be 500 feet of sediment.

2. *Central (Mine) group.*—Including the "Greenstone group," the "Phoenix Mine group," etc., but only a part of Pumpelly's "Portage Lake series," and just about that part included and well exposed in the workings of the Central mine on a cross-fissure, exposing a good section, examined by Pumpelly and Hubbard, and more recently supplemented by diamond-drill cores on the same property (sections 24, 25, 36, T. 58 N., R. 31 W.). This is a new name we would introduce and define as extending from the Bohemia conglomerate, Marvine's conglomerate (3) or (8) to the "St. Mary's epidote," a sediment, volcanic ash, just above the "Greenstone" and Marvine's conglomerate (15). Characterized by very heavy flows of ophite, some of them hundreds of feet thick, so that, for instance, the "Greenstone," the one at the top of the series, extends beneath Lake Superior, from one side to the other; often proportionately coarse grained.

On Black River there are possibly 25,000 feet including flows. At Portage Lake (7,882), say 8,000 feet.

3. *"Ashbed" group.*—This group has been named from the Ashbed Mine, or really originally from a lode so called by the miners, worked at that mine, Marvine's (*a*) and (*b*), Irving's (5) and (6). Including conglomerates 16 to 18, characterized by frequent glomerophyric that is relatively feldspathic and fine grained flows.

In the Tamarack shafts.....2,400 ft.

The amount of well-marked conglomerate is not over 50 feet but

the amygdaloids shade into beds of scoria mixed with red mud called "ashbeds."

4. *"Eagle River" group.*—Marvine's (*c*), characterized by waning volcanic activity shown by numerous (10 or more) sandstones and conglomerates, while the interbedded flows are more of the normal type. In the upper 2,300 feet Marvine estimates 860 feet of sediment. On Black River it is given as 1,417 feet; at the Tamarack as 1,700 ft.

5, 6, and 7. *Copper Harbor conglomerates.*—The conglomerates north of the Eagle River Group were grouped together by Douglass Houghton, who considered the Lake Shore Traps as intrusive dikes. When these were understood to be interbedded flows, the conglomerate was divided into the Great and Outer, respectively, below and above the Lake Shore traps. Hubbard's studies around Copper Harbor have shown that there are at least three heavy conglomerates. It is not probable that the lines between the Great Conglomerate, Lake Shore Trap, and Outer Conglomerate can be drawn at all consistently. Together they cover the period of decadent vulcanism, and it is not at all likely that the flows from these last expiring throes filled the whole basin but more likely they occur irregularly in the conglomerate series. It therefore seems fitting to give a local term to the whole assemblage, treating the Lake Shore traps as a lentil or lentils in the same.

5. *"Great" conglomerate.*—Its thickness, not allowing for initial dips, is say 2,200 feet at Eagle River and Calumet, but apparently much less, 340 feet, on Black River. It has a wide variety of pebbles, but mainly of Keweenawan rocks.

6. *Lake Shore Traps.*—These are apparently thickest near Copper Harbor where using Hubbard's figures, they are about 1,800 feet thick. They are near 900 feet thick at Calumet, but at Black River are only about 400 feet thick. There is at least one well-marked conglomerate in the group. Above this group is the line between the Upper and Lower Keweenawan as drawn by Irving, marked by a cessation of volcanic activity. There are also less dips in general, and very soon a greater variety in detritus.

7. *Outer conglomerate.*—With pebbles representing all the Lower Keweenawan types, including intrusives, amygdules and agates, and also the Huronian jaspilites. Only 1,000 feet are given at

Keweenaw Point, but to the Nonesuch shale on Black River it must be much thicker, not allowing for initial dip at least 3,500 feet. Irving estimates 3,000 feet in the Porcupines.

8. *Nonesuch formation* (from the Nonesuch mine).—Dark colored shales and sandstones—owing its dark color to the basic material—a very significant sign of heavy erosion of Keweenawan traps at some distance. This seems to be a very persistent horizon in lithological character, in spite of not being very thick, being 600 feet on the Porcupines, 500 feet on Black River, and 350–400 on the Montreal.

9. "*Freda sandstone.*" "Main body of sandstone" or "western sandstone" of Rominger (*not* Irving). This seems to need a local name and may well take it from the new stamp-mill town on the shore of Lake Superior, not far from Portage Lake Canal, near which exposures occur, and a well showed a thickness of over 970 feet of sandstones and shales. The relation of this to the "Lake Superior sandstone" in general is a mooted question. It was included in it by early writers. It is much like it lithologically and structurally though felsitic and basic débris and streaks of red clay may be rather more common and the water more saline than in the Lake Superior sandstone around Marquette. The one mantles a granitic boss from which the other was separated, as the Nonesuch shale shows, by extensive exposures of Lower Keweenawan.

Wells in unquestioned Lake Superior sandstone at Lake Linden and Grand Marais show that it is 1,500 feet and over thick. The dips are generally less than those of deposition, so that we cannot make much use of them. Irving estimates the thickness at 12,000 feet, but this is, we believe, based solely on the questionable Montreal river section. We do not, however, think, that it will be decreased below 4,000 feet, if we allow 1,500 feet to the Lake Superior sandstone and make 8,000 feet for the whole upper Keweenawan. We repeat that we are not at all sure that there is any other than an arbitrary dividing line between it and the sandstone which we propose to call Jacobsville.

Lake Superior sandstone.—This term was used by Houghton, and has been customary since, the term Sault Ste Marie sandstone being much later and less used. It is often and quite properly called the Potsdam. It is necessary only to refer to the supposed equivalence

with the "New red" Triassic sandstones, held by Jackson, Marcou,[1] and for a time Bell. But accepting its approximate equivalence and even continuity with the Potsdam, there still may be a question as to its exact horizon, which can not be exactly the same everywhere, and might be widely different. It is readily divided in outcrop and in wells into a redder and lower portion and a whiter upper portion. The line between the two may mark the epoch of submergence of the iron-bearing rocks, only a few islands of granite and quartzite, remaining exposed to erosion. In view of the uncertainty of the relation of the three parts of the Lake Superior sandstones, as used by Houghton, separate names seem to us likely to be useful, and we propose not only the term Freda sandstone for that west of the Copper Range, but the term Jacobsville (from Jacobsville where the famous quarries of Portage redstone occur) sandstone for that east of the Copper Range, and we suppose this term may apply to all the Lake Superior sandstone skirting the coast at intervals to Grand Island, while the term Munising sandstone is to apply to the upper 250 feet of Lake Superior sandstone which crosses the bluffs back of Munising, dips southerly, and is white or light colored. Houghton considered the upper "gray sandstone" (700 feet ?) to be unconformable on the lower, dipping south to southeast, while the lower dips to the north. The upper part is well ripple-marked, cross-bedded, friable, with *Fucoides* (?) *duplex* and *Lingulepis prima*, and *L. antiqua*. *Dikelocephalus misa* (?), *Dikelocephalus* (Hall, Pl. XXIII, 3*a*–*e*, 4), and *Lingulepis primiformis* occur at Iron Mountain which Walcott told Lane was of the Ptychaspis zone. At Marquette Murray reports *Pleurotomaria laurentina* (?) and Scolithus and beds similar at Campment d'Ours close under the Trenton. At Limestone Mountain, below the fairly extensive Trenton fauna, are some conglomeritic beds before we come to the main mass of sandstone. Logan (followed by Grabau)[2] mainly on the strength of the (en)Campment d'Ours Island section concludes that the Lake Superior sandstone may "represent the Chazy, Calciferous, and Potsdam." Beside the Campment d'Ours Island section the Neebish well also indicates a great thinning of the section below the Trenton to the pre-Cambrian along St. Mary's river. But the question remains whether it is by a dis-

[1] *Bull. Geol. Soc. Trans.*, Vol. XXXII, p. 102.

[2] *B. G. S. A.*, Vol. XVII, pp. 582, 617.

conformity and erosion of the Calciferous and St. Peter's down to the Lake Superior sandstone, so that at least most of the sandstone below the "Trenton" limestone is Cambrian and represents the Lake Superior sandstone generally, or whether this sandstone represents the St. Peter's sandstone, the "Potsdam" and Calciferous having been overlapped, or the latter by a shoreward change of facies passed into a basal sandstone, which might represent continuous transgression of the ocean. The St. Peter sandstone is well marked at the Wisconsin line, with a good 200 feet of Calciferous (Lower Magnesian dolomite) under it and also, as records just arrived show, at intervals along Green Bay, at least as far as Rapid River. The Calciferous certainly continues as a thick, well-marked formation well beyond Calciferous station and creek, and according to Rominger clear to T. 45 and 46 N., R. 1 W., and Neebish (Anebish) Rapids. Moreover a few scattered wells to rock as at Newberry in the center of the peninsula do not record any St. Peter's. All these facts favor the first interpretation independent of the fact that it seems to fit better with Berkey's interpretation of the St. Peter sandstone, though to be sure it implies a disconformity at Campment d'Ours Island.[1]

As has been said the total thickness of this sandstone and the extent to which it is equivalent to the Freda and Upper Keweenawan sandstone are conjectural. As it laps upon the areas of older rocks its thickness diminishes to nothing, and there is often a conglomerate at its base. Its composition is largely quartz and feldspar of the acid varieties, sometimes up to 37 per cent. of orthoclase and microcline. The absence from the formation, except immediately at its contact with other formations, of much basic or even a large amount of felsitic débris which is more abundant in the Upper Keweenawan, is one of the reasons why we believe there can be no great discordance or time interval between this and the Upper Keweenawan. It seems to mark the culmination of the same general depression, when only the granite cores were exposed and finally even these were covered. The upper sandstone which Houghton called the "gray sandstone" he estimated at 700 feet thick. Wells indicate only some 250 feet. The change may indicate that the transgression had gone so far as practically to bury any iron-bearing rocks.

[1] Cf. Rominger, Vol. I, Part 3, pp. 64, 76, 77, 82, and 83.

Calciferous formation.—This formation appears to have been called by Houghton the sandy limerock, and was said to occur at several points on Sailor's Encampment Island (not Campment d'Ours) near West Neebish Rapids. On Foster and Whitney's map of Lake Superior it was called the Calciferous, a name which it has since generally retained (Winchell's map, 1865, Brooks, Pumpelly, and Rominger's map 1873, and the state survey since, *U. S. G. S. Monograph 36*, 1899, etc.), and has indeed become imbedded in the local nomenclature of Calciferous Creek, a branch of the Au Train river, and Calciferous, a station on the Marquette and Southeastern R. R., so that it may be retained even as a geographic name. "Lower magnesian limestone" has from time to time been used as synonymous. The Hermansville limestone of the *Menominee Special Folio and Monograph*, pp. 31, 494 (Bayley, 1900–04) is this formation, or some part of it. It is given as not over, but near to, 100 feet thick, and equivalent to the Chazy and Calciferous of the east on Rominger's authority. The wells along the Green Bay shore, however, show a fairly constant maximum thickness of about 250 feet. Here flowing wells reach the Lake Superior sandstone between 600 and 700 feet. A late record from Marinette shows, however, 75 feet of white sandstone at the top which may be a trough filled by St. Peter sandstone. The interesting record is in brief:

Quaternary sand	69– 69
Galena and Trenton	256–325
Blue and brown limestones and dolomites	
Sand at 260′, red shale at 290′ (St. Peter horizon?)	
St. Peter (?)	
White sandstone	75–400
Calciferous	
Brown dolomite	60–460
White sandstone	70–530
Dolomite (Hermansville)	50–580
Lake Superior sandstone	
Upper, white sandstone	195–775
Lower, pink, shading into conglomerate of cherty quartzite, base uncertain	95–870
Huronian	
Cherty quartzite?	108–978

It looks as though thus close to the Archean land mass the formations were much broken by unconformities and sandstones (of course allowance must be made for imperfect records), and perhaps the term Hermansville will be fittingly applied to the lower 50 feet of the Calciferous. We may compare the triple division of the Calciferous, with the Shakopee dolomite, New Richmond sandstone, and Oneota dolomite of Minnesota.

11. *St. Peter sandstone.*—Outcrops of this have never been identified in Michigan. But the Green Bay wells show a constant water-bearing horizon at about the level where it should appear, and occasionally sandstones, or red clays, and residual dolomites. At this formation we break the column. It is the top of that part exclusively known or seen in the Upper Peninsula. It marks a break which Rominger and others considered the important break which should mark the top of the Cambrian.[1]

[1] See Berkey, *B. G. S. A.*, Vol., XVII, pp. 229–50.

NOTES ON THE JAMAICA EARTHQUAKE

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INTRODUCTION

The following notes on the Jamaica earthquake are based upon observations made by the writer during a visit to Kingston in March, 1907, and upon interviews with government officials and others who were present in the city at the time of the disaster. Special thanks are due to Mr. Robert Simmons, A. I. C., of the Government Laboratories for information furnished, and to Mr. F. G. Clapp of the United States Geological Survey, who was associated with the writer in his studies and who has supplied several of the photographs accompanying the present paper. Owing to the shortness of the stay at Kingston the observations were of necessity somewhat limited, and no claim for completeness can be made, the object of the paper being simply to present some of the more important results of the earthquake as observed by the writer or described to him by eye-witnesses.

The city of Kingston is located on the south side of Jamaica, on the seaward edge of a large alluvial fan, occupying a V-shaped re-entrant in the mountains. In front of it is a spacious harbor, separated from the open sea by a long sand-spit, stretching westward for a distance of eight miles from the mainland, at a point about four miles southeast of the city. The relations are shown in Fig. 1.

GEOLOGY

The island of Jamaica consists essentially of an east-west core of metamorphosed Cretaceous shales, conglomerates, serpentine limestones, etc., standing at high angles and cut by granitic intrusions, surrounded by a narrow belt of younger and less disturbed Cretaceous sands, marls, and limestones, around which in turn is a wide belt of Eocene limestones, etc., with a few patches of Neocene around the edges. The structure is anticlinal, the trend of the uplift being from a little north of west to south of east. A considerable number

of faults occur with trends parallel to the structural ridge while others are approximately at right angles to it. Large alluvial fans are found in indentations of the mountains at many points.

TOPOGRAPHY

In a general way the topography depends on the geologic structure, the mountainous areas corresponding with the upturned meta-

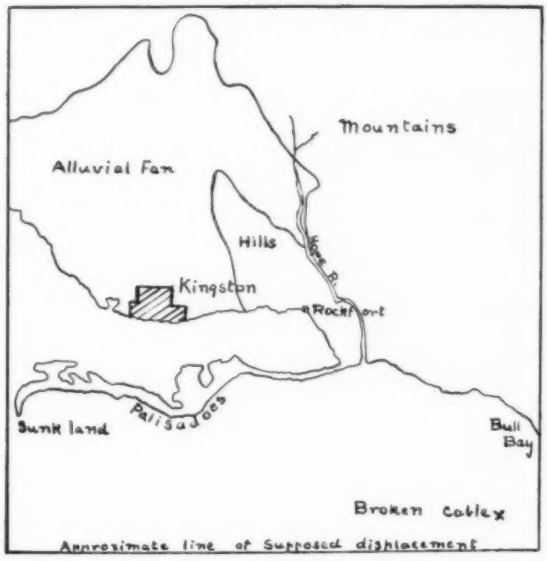

FIG. 1.—Sketch map illustrating location and surroundings of Kingston, Jamaica.

morphic tracts and the broad plateaus bordering the mountains, especially to the west, coinciding with the younger and less disturbed Eocene beds.

GENERAL SEISMIC CONDITIONS

Seismic disturbances have been of frequent occurrence in the island of Jamaica since its settlement, but in general the shocks have been of slight intensity. In 1692, however, an earthquake of great severity took place, engulfing such parts of the city of Port Royal as were built upon the sand-spit across the harbor opposite the present

site of Kingston, and seriously damaging smaller areas built on the limestone reef. In the 200 years following this great shock the island was shaken from time to time by minor disturbances, some of which were of some intensity, but no record seems to have been kept until the latter part of the last century. The records available to the writer[1] covered the period from February 19, 1880, to November 25, 1906, during which 163 shocks were felt. Their distribution, which is shown in the accompanying table, indicates a maximum in the autumn and winter months with a minimum in the spring and summer months. The activity shown in the last column is computed by assuming that two shocks of Intensity I are equal to one of Intensity II, and that two of Intensity II equal one of Intensity III. In other words, I equals one, II equals two, III equals four, IV equals eight, etc.

From the table it will be noted that the activity is 198 in the night hours (6 P. M. to 6 A. M.) as compared with 150 in the day (6 A. M. to 6 P. M.). The principal activity is from 2 to 5 o'clock in the morning with a lull at daybreak followed by a marked increase in the activity from 7 until 9. From 9 until 1 there are very few shocks, but from 2 to 4 the number is again high, after which it drops to a very low point from 5 to 7 o'clock. In the evening there is a strong rise between 8 and 10 o'clock, after which there is a falling off until the 2 to 4 o'clock period the following morning. This early morning period of activity (2 to 4 A. M.) corresponds with one of the minima of the diurnal variations of barometric pressure. The forenoon period of low activity, from 9 to 11, corresponds with the forenoon maximum; the afternoon period of intensity, from 2 to 4, with the corresponding barometric minimum. Up to this point the disturbances agree with that postulated by the advocates of greatest activity during barometric minima with least activity during the maxima. The evening period of barometric maximum, which according to theory should be a period of minimum activity, however, is in reality one of great activity, while the least activities of all are found at daybreak and sunset when theoretically they should be of intermediate activity. These variations are not confined to the Jamaica earthquake, but have characterized others, especially the New Madrid earthquake of the Mississippi Valley in 1811, the record of the shocks of which

[1] Maxwell Hall, published in the local press, February 18, 1907

were carefully kept during the period of disturbance, which lasted over a year. The table of these shocks shows nearly the same features throughout as the tabulated data above. Just what the factors are which give rise to the peculiarities of distribution are not known, but they appear to be of a general rather than a local nature.

SEASONAL DISTRIBUTION OF JAMAICA EARTHQUAKES, 1880–1906

	I	II	III	Activity
Spring (March, April, May)	21	10	1	45
Summer (June, July, August)	16	11	1	42
Autumn (September, October, November)	41	11	2	71
Winter (December, January, February)	35	9	5	73

DIURNAL DISTRIBUTION OF EARTHQUAKES

Based on 163 shocks previous to November 25, 1906, and 90 shocks after that date

Hour	I	II	III	Activity
12 M.	7	2	1	15
1 A. M.	3	3	1	13
2 A. M.	11	5	2	29
3 A. M.	13	9	..	21
4 A. M.	8	2	..	12
5 A. M.	9	5	..	19
6 A. M.	7	1	..	9
7 A. M.	12	3	1	22
8 A. M.	10	1	..	12
9 A. M.	5	3	..	11
10 A. M.	6	..	..	6
11 A. M.	7	..	..	7
12 M.	9	2	..	14
1 P. M.	6	2	..	10
2 P. M.	9	3	1	19
3 P. M.	4	4	2	20
4 P. M.	7	2	..	11
5 P. M.	5	2	..	9
6 P. M.	5	1	..	7
7 P. M.	6	1	..	8
8 P. M.	4	4	1	16
9 P. M.	11	1	1	17
10 P. M.	12	4	1	24
11 P. M.	9	1	1	15

Of the disturbances preceding the principal shock, that occurring in November, 1906, was the most severe, rattling dishes, shaking a few bottles, etc., from shelves, and producing slight cracks in a few instances, being a stronger shock than any subsequent to the main disturbance.

THE RECENT EARTHQUAKE

WEATHER CONDITIONS

At the time of the recent severe shock, which occurred a little after half-past three in the afternoon, the barometer stood at 29.551, which is normal for the locality and elevation. The weather was clear. The shock occurred near the date of the new moon at which period, it is claimed by some, the Jamaica earthquakes are particularly likely to occur, owing to the supplementary attraction due to the conjunction of sun and moon. A comparison with the table above also shows that it took place near the afternoon period of maximum intensity.

TIME AND DURATION

The principal shock, which was the only one producing any serious damage, took place at 33 minutes and 6 seconds past 3 o'clock in the afternoon of January 14, 1907, and lasted about 30 seconds. The vibrations were not of uniform strength, but were marked, according to descriptions, by at least three recurrent pulsations of alternating low and high intensities.

CHARACTER OF MOVEMENT

Direction of vibrations.—Those who experienced the shock in Kingston are generally of the opinion that the vibrations were along an east-west line, but whether from the east or from the west there is some disagreement. That the principal movement was along the line indicated is further attested by the fact that the east and west ends of buildings were most commonly thrown down, east and west walls more frequently buckled and crushed, and cracks in the walls mainly in east and west directions. As will be seen later the epicenter was very near Kingston, and there was more or less deflection of the waves by the surrounding mountains, doubtless giving rise to complications of movement which more or less disguised the normal direction of transmission.

Nature of vibrations.—The nature of the earth movements depended largely upon the character of the underlying material at the point where the shock was observed. On the solid rocks and on the compact semi-cemented alluvium on which Kingston is situated the

movements were of the short, sharp, tectonic type, there being practically nothing in the nature of the undulatory surface wave. At Port Royal, on the other hand, the surface waves predominated,

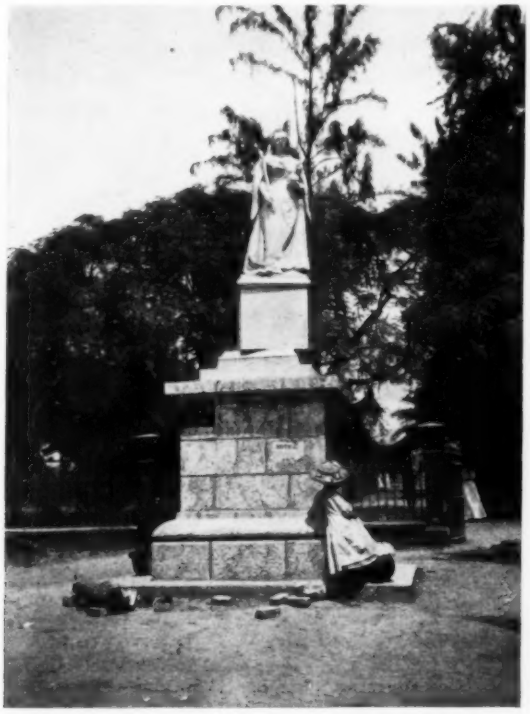

FIG. 2.—Southward facing statue of Queen Victoria, twisted in anti-clockwise direction by tortional movements. (Photo by Fuller.)

the ground rising and falling as the movement progressed in the same manner as do the waves upon the sea.

The seismographs were put out of commission at the beginning of the shock, and for the nature of the shock personal observation must be depended upon. According to the accounts of those who were interviewed by the writer, the first vibrations seemed to come

from below, the action somewhat resembling in effect the feeling one might experience if the floor on which one was standing were subjected to a hard blow from underneath. This was apparently followed by a rapid motion from side to side, and finally by a tortional motion which is described as shaking objects much as a terrier shakes a rat. It was this motion which produced the twisting exhibited by nearly all statues in the city (Fig. 2). As already indicated, there were three or more maxima of intensity during the shock. A feeling of intense confusion was experienced by those feeling the shocks but nausea was seldom produced.

Intensity and amplitude of the vibrations.—The amplitude of the vibrations appears to have been small. Only in occasional instances were street cars shaken from the tracks, few of the statues were overturned, and only a small number of telegraph, telephone, or trolley poles were overthrown or tilted. This would hardly have been the case if the lateral movement had been considerable. As nearly as can be judged from descriptions the movement was not over an inch.

The intensity of the shock, as attested by the ruins, however, was very high, the destructions being to a considerable extent due to a sort of disintegration, apparently resulting from very strong and rapid vibrations, which, however, were of short amplitude, at least in the rock areas and the stiff semi-compacted alluvium of the Kingston region.

ASSOCIATED PHENOMENA

Noise.—The earthquake was accompanied by a loud noise, described as a deep crushing sound, somewhat suggesting distant thunder but with less boom and more of a roar. Intermixed with the natural sounds proceeding from the earth was the crashing of the buildings and the cries of the people, the two together being described as almost deafening.

Dust.—One of the phenomena described by all eye-witnesses was the notable darkness following the shock. The local mortar, rather poor at the best, which was used in most of the buildings, pulverized quickly, and was projected into the air together with other dust in immense quantities as the buildings fell, saturating the atmosphere until it was almost impenetrable to the suns rays. After the cessation

of the shock it slowly settled, covering everything with a thick white mantle of fine calcareous silt.

EFFECT ON INHABITANTS, ETC.

Behavior during earthquake.—The greater part of the inhabitants of the island of Jamaica are negroes or mulattoes, although a very considerable number of whites reside in the cities, especially in Kingston and Port Royal. The negroes, although Christianized, retain

FIG. 3.—Wreckage in area of severe disturbance. In places the ruin was so complete that streets could be traced only with difficulty. (Photo by Cleary's Studio, Kingston.)

many of their superstitions and are very demonstrative, a fact which had an important bearing on their behavior and attitude during and subsequent to the earthquake. The very first shock threw them into the greatest fright, but it was far from a paralyzing fright either as regards speech or motion, for the majority fled precipitately from their houses into the streets and open places as a howling mob, alternately screaming and praying, sometimes, it is said, both at once. Even after the vibrations had ceased the excitement and noise continued for some time, and the greatest confusion prevailed. The police and troops were soon out, however. and the wrecked district

was carefully patrolled, no one without a pass being permitted to enter. Throughout the shock the whites behaved with a considerable degree of calmness, being without the unreasoning fear which characterized the blacks, yet none could reach the open too soon. Animals, wherever not thrown down by the shock, generally stampeded, horses, mules, and cattle being alike in this respect.

Loss of life.—The loss of life on the island, as compiled from identified remains and the list of missing, is officially given as 1,003, almost the whole number of casualties being at Kingston or vicinity. The high death list resulted from the fact that the shock occurred late in the afternoon when the stores and sidewalks were full of people. The loss in some of the stores was very large, that in the "Beehive," "Army and Navy," "Waterloo House," and "Croswell's" being greatest. From 25 to 40 sometimes lost their lives in a single store. At the Jamaica Club 7 out of 9 were killed, while in other buildings, like the Colonial Bank, everyone escaped. Many lost their lives upon the sidewalks, crushed by the falling buildings. The loss was greatest in Port Royal Street, Water Lane, and vicinity, which was one of the most completely wrecked districts, the position of some of the streets being hardly distinguishable amidst the rubbish after the shock. Few people in this vicinity escaped uninjured. So great was the destruction and accumulation of débris that at the time of the writer's visit, two months after the shock, bodies were still being recovered from the ruins.

Outside the city and vicinity the loss of life was not great, although a few people among the mountains were killed by falling rock or landslides. Of the deaths many were instantaneous, but many persons were caught in the ruins and burned in the conflagration which followed the shock. Twenty or thirty died subsequently from blood poisoning resulting from improperly dressed or neglected wounds. No epidemic of sickness has yet appeared.

EFFECT OF EARTHQUAKE

The results of the earthquake varied considerably according to the nature of the material constituting the surface at a particular point. Rock areas, alluvial fan deposits, and sand-spits are the principal types involved.

ROCK AREAS

Land slides.—The rock areas near Kingston are confined principally to the mountains, the narrow border of coastal plains being of unconsolidated materials. In the rock areas the surface is composed of

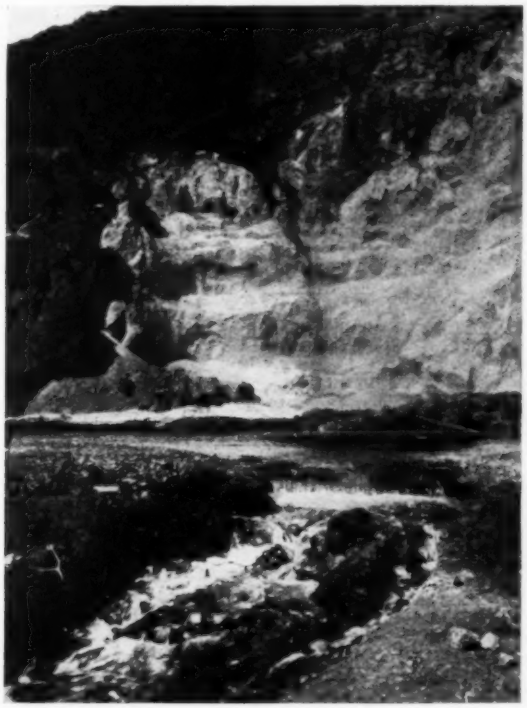

FIG. 4.—View of large spring (400 gallons per minute) resulting from rock fractures in soft limestone at Rockfort quarry. (Photo by Fuller.)

disintegrated rock, bowlders of disintegration, etc., forming a mantle or talus over the hillsides. The slopes in many instances are very steep, and as a result of the earthquake many bowlders and avalanches were precipitated down the mountain sides, leaving great bare scars on their faces. In many cases trails were obliterated and roads ruined by slipping or by coverings of débris and, as already mentioned,

a few people were killed. In the large government quarry at Rockfort east of Kingston large pieces of the walls were broken down forming large heaps of débris.

Outbreak of springs.—Previous to the earthquake a single large spring had flowed from the limestone at the base of the quarry at Rockfort, but at the time of the shock a second spring, as large or larger than the original, broke forth through fractures produced at the time and flowed to the sea as a stream between three and four feet wide, five or six inches deep, and with a velocity of several feet per second. The water is salty and slightly thermal, and at times is said to be somewhat sulphurous.

ALLUVIAL DEPOSITS

Character.—The alluvial deposits, upon which Kingston was built, consist mainly of a gravel with a stiff, reddish, sandy clay matrix, binding the whole into a somewhat tough resistant mass. Geologically it belongs to a broad alluvial fan occupying a re-entrant in the mountains and rising from sea level at Kingston to an elevation of several hundred feet at the base of the mountains. Throughout the fan, except near its seaward edge, the ground water is rather deep and had but little effect on the phenomena of the earthquake, the material behaving, in fact, much like solid rock, being almost entirely without the warping, fissures, etc., such as usually characterize unconsolidated materials.

Earthquake fissures.—From the fact that the movements were of the nature of vibrations rather than visible earth waves it was not to be expected that fissures would be produced to any extent upon the mainland. In fact, it was only near the margins of stream gullies and along the sea margin—points where there was an opportunity for lateral displacement—that fissures were formed. Of the displacements along stream banks, those near the Hope Culvert were among the most pronounced, the aqueduct bearing a part of the city water being broken by the movement at this point. Along the water front the fissures were more numerous. Near Victoria Market, especially, a considerable number of small fissures parallel with the sea margin were formed, from which considerable amounts of sand and water were extruded. The latter, however, were from no great

depth as the water level is here within a few feet of the surface. The locality on the mainland where the cracks are most numerous seems to be east of the city between the end of the trolley line and the government quarries at Rockfort. At this point the shock was not

FIG. 5.—Earthquake cracks due to lateral displacement toward the sea, near Rockfort, Kingston. (Photo by Fuller.)

only more severe, but the road built on an artificial shelf at the water's edge and only five feet above it, offered especially favorable conditions for fissuring. Cracks were observed along this road for a distance of half a mile. Some were less than five feet in length and only about one inch in breadth, while others up to one hundred feet or more and with a width up to four inches were noted. Most of the cracks were irregu-

lar gaps, originally extending downward to the level of the sea from three to eight feet below. An interesting feature, however, was presented by the absolutely straight and regular fissures, sometimes fifty or more feet long, and determined by the line of excavation made

FIG. 6.—Earthquake crack due to lateral displacement along line of old sewer excavation. (Photo by Fuller.)

years before for the sewer. In all cases the fissures were parallel to the water front and resulted from the separation of a narrow strip along its margin, generally slightly displaced and somewhat tilted toward the sea.

Faulting.—Very little faulting took place in the alluvial deposits,

although slight displacements took place along some of the fissures. In one instance near Rockfort the road along the shore seemed to have fallen with reference to the sidewalk a distance of four to six inches, and at other points a sinking of the road of from one to two feet, doubtless owing to flowage of the underlying sand, seems to have occurred. In other cases the motion appeared to be the reverse, the segment containing the sewer sinking with reference to the road.

Extrusion of sand and water.—As already mentioned more or less sand and water was extruded from fissures near the water front at the Victoria Market, but, owing to the toughness of the alluvium, the depth of the water table, and the absence of large earth waves, the conditions were unfavorable for such action. No craterlets were reported, and there appears to have been no extrusion from the cracks along the Rockfort road as described above.

Change of level.—No noticeable change of level of the land, except in the fissured and slumped zones at the immediate margin of the sea has been recognized. So far as can be determined the water stands at the same level along the wharves as before the shock.

SAND SPIT (PALISADOES)

Extending from the mainland about four miles east of Kingston a long spit known as the Palisadoes stretches westward, a distance of eight miles, forming the harbor of Kingston. Patches of reef limestone representing original islands, reach the surface of the spit at at least two points. With the exception of these rocks the entire mass is composed of loose wave- and wind-drifted sands, standing only a few feet above sea level and saturated with water nearly to the surface. The conditions for the propagation of earth waves and for disintegration and slump were, therefore, far more favorable than in the tough alluvial deposits at Kingston, and, as would naturally be expected, the destruction was much more severe. On the limestone patches, on the other hand, the action was similar to that on the mainland.

Fissures and extrusions.—Fissures and extrusions of sand occurred at various places on the Palisadoes, especially near the point of connection with the mainland. Here long lines of closely spaced faults parallel to one another and to the sea margin were formed. The

displacements of the individual faults was usually only from six inches to a foot, but the aggregate displacement amounted to many feet. Along some of the fault lines large quantities of sand and water were extruded, the points of emergence being now marked by long narrow craterlets. More or less fissuring and extrusions of sand are also said to have occurred at the end of the point at Port Royal, the cracks apparently opening as the crest of the earth wave advanced and closing (accompanied with the extrusion of sand and water to a height of several feet) as the crest gave way to the following trough. Most of this action was on the part of the point which finally sunk below the sea (Fig 7.).

Tilting and warping of surface.—Owing to the same incoherent nature of the materials there was not complete recovery from the earth waves, the surfaces at many points remaining in the form given them as the waves progressed. An even more important effect, however, appears to have been produced by the flowage of the saturated sands. The result of the two was to leave the surface bent and warped, a condition brought out strongly by the present attitudes of the artificial structures. Near the end of the point, as one enters the harbor, a wooden tower is observed tilted several degrees and the gun foundations equally out of level. On the inside of the point the sea wall is likewise tilted at a considerable angle, and one of the wharves is similarly inclined. Several of the flagpoles are much inclined and numbers of houses noticeably tilted, while in one case the middle of a building seems to have sunk several feet with reference to the ends, breaking it from bottom to top along the center. The railroad tracks at one point are reported arched up for a distance of twenty-five yards, the elevation of the center above the ends being estimated at about four feet, while lateral twists in the tracks were not uncommon. In some localities arches in the surface with angles from 3° to 10° are said to occur.

Subsidence and submergence.—The tilting and warping described in the last paragraph resulted from differential movement, parts of the surface being lifted while other parts sunk. In many instances the subsidence was sufficient to bring the bottom of the cellar below the level of the ground water so that water now stands above their floors. At one point on the north side of the Palisadoes the sinking

was such that a lagoon formerly separated from the salt water by a beach twenty yards in width and two or three feet high was covered by the sea. Perhaps the most conspicuous change of level was at the extreme south-west point of the Palisadoes at the entrance of the harbor, where a body several hundred feet in length and breadth sunk beneath the waters of the ocean. Fig. 7, which represents a view of this point, shows the palm trees and shrubs, still upright,

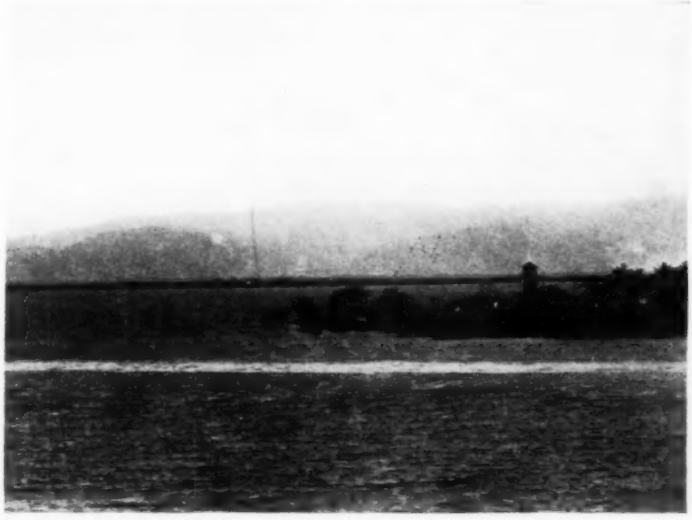

FIG. 7.—Submerged land at southwest termination of the Palisadoes at Port Royal. (Photo by Fuller.)

projecting from the water. The subsidence, which here seems to have been from ten to twenty feet, was probably due to a sort of flowage of the loose water-saturated sands underlying the surface at a depth of a few feet. A mangrove swamp on the harbor side of the Palisadoes is reported to have sunk ten feet.

In addition to the cases mentioned, what may possibly be a case of subsidence was seen from the steamer off Morant Point at the east end of Jamaica, some forty miles from Kingston. The shore at this locality is low for some distance, only a narrow strip of beach

showing between the water and the forest which here comes to the shore. In a few places this beach, as seen from a distance of not over a mile, seemed to be missing, the water reaching amongst the trees, the foliage of which appeared to be dried and withered as if recently killed by a subsidence which had admitted the sea.

EFFECT ON SEA BOTTOM

Kingston harbor.—Immediately following the earthquake many stories were circulated as to the obstruction of the harbor by mud flows, etc., but soundings in its channel showed that it had not been materially altered and vessels of deep draft soon entered and left as usual. Inasmuch as the bottom is prevailingly soft, and as the soft materials at Port Royal were much disturbed, there was doubtless much flowage wherever the bottom possessed any considerable inclination. The action was most marked, along the shores of Port Royal, where the bordering bottom sunk many feet in places, accompanied by a corresponding rise at a point farther out, or by at least an outward flowage of the soft deposits.

Sea bottom off coast.—On the sea bottom there appears, on the contrary, to have been disturbances of great magnitude, the center being, it is stated, some three or four miles off shore at a point southeast of the mouth of Hope River at the east end of the Palisadoes where they are attached to the mainland. In this locality the bottom is reported to have been decidedly roughened by movements of its soft materials, resulting in the breaking of the cable at points from three and one-half to fifteen miles off the coast. Several miles were so twisted, broken, or buried that new cable had to be laid. No such action occurred anywhere on or near the land, and, if accounts are to be relied upon, this is to be regarded as the region of greatest disturbance.

EFFECTS ON FORESTS

The action of the Jamaica earthquake on forests was relatively slight. On the mountains a few insecurely rooted trees were more or less tilted and some dead trees are reported to have fallen. The chief destruction, however, was by avalanches which not infrequently made paths many feet wide for several thousand feet down the mountain sides. On the Palisadoes and in similar situations where the

surface caved or sunk beneath the sea, many trees were submerged and killed by the salt water. The possible submergence of considerable areas in this way at Morant Point was suggested on a previous page.

EFFECT ON ARTIFICIAL STRUCTURES

Kingston

The intensity of the Jamaica earthquake was very great and the destruction correspondingly severe, the ruin apparently being equal to, if not surpassing, that in the Charleston and San Francisco earthquakes in our own country. While some high buildings escaped complete demolition, nearly all were badly wrecked, while in many cases even the one-story houses and stores were destroyed. The destruction was not uniform, however, varying greatly according to the nature of the materials used in construction. In the order of their resistance the structures were of steel, wood, stone, concrete, and brick.

Brick structures.—In the brick structures some of the most interesting forms of destruction were exhibited by the posts forming parts of the fences found in front of a great number of houses. The usual method followed in the construction of the fence was the erection at intervals of from ten to fifteen feet of square brick posts, about one and one-half feet in diameter and five or six feet tall, between which iron or wooden picket fences were placed. When the vibrations struck the fences the brick posts were in 90 cases out of 100 broken off at their base, falling en masse at right angles to the fence, especially where it ran in a north-south direction. In several instances the brick posts were thrown out of the fence, leaving the wooden palings standing. On the east-west streets the posts were sometimes thrown toward each other, crushing the wooden or buckling the iron fences between. Besides the destruction of the posts en masse some were disintegrated by the shock, the bricks of the center being loosened and causing a marked bulging. A few more vibrations and the whole would have crumbled.

The destruction of the brick garden walls was also severe, everything over 3 feet in elevation being generally badly injured. On north-south streets there was a tendency to fall en masse, while in

east-west streets, tortional warping, disintegration, and the breaking away of large chunks was common.

FIG. 8.—Wrecked church tower. Note clock stopped at 3:35. The tower has since fallen. (Photo by Cleary's Studio, Kingston.)

The action on brick buildings was variable. The better class stood in some cases through both shock and fire, although the motion was sufficient to snap flagpoles at their tops. The churches fared very badly, most of them, even where not completely demolished, being practically ruined, the damage being such that they had to be pulled down (Fig. 8). The fact that they had little interior strengthening in the way of partitions probably contributed to this result. The cracks generally meandered irregularly, but approximately diagonally through the brick walls, commonly making an angle of about 45° with the horizon. In other cases the action seemed to be largely one of disintegration, the latter being assisted by the rather poor local mortar commonly used. In general the destruction on the north-south streets seemed more complete than in the east-west streets.

Stone structures.—There were relatively few stone structures in the city or vicinity. Of these the Government Laboratories, several miles away, were almost unaffected, only a few small cracks, not necessitating repair, being developed. At the Colonial Bank, composed of stone and brick, the destruction was greater, but none of the occupants was killed, while many in surrounding brick buildings lost their lives.

Cement structures.—Only one cement structure was seen by the writer. This was the building of the Jamaica College, situated near the Government Laboratories just mentioned. Unlike the latter, however, it was so badly wrecked that a portion had to be pulled down and the whole practically rebuilt. The action was one of cracking rather than of disintegration. The cement was not reinforced to any extent.

Wooden structures.—The frame houses were considerably wrenched and twisted by the shock, and their plastering was often cracked or shaken down, but, owing to their elasticity, they generally escaped demolition, and after cleaning and a few repairs were ready for reoccupancy. A few wooden buildings were wrecked, however, in the eastern part of the city where the action was especially severe.

Steel structures.—There were no steel office buildings in the city, but two markets, the Victoria on the water front (Fig. 9) and a similar one near the public square were built mainly of this material. They

were little affected by the shock, presenting almost no outward signs of disturbance, although the former was near the water's edge where the ground was much agitated and small fissures opened. They were still usable after the shock.

Combination buildings.—The type of dwelling having a lower story of brick and an upper story of wood was very common at Kingston, but was, unfortunately, not adapted to resist the earthquake disturbances. The brick portion was invariably damaged and in a

FIG. 9.—Showing complete demolition of brick tower while wooden porches are unaffected. (Photo by Cleary's Studio, Kingston.)

great many cases collapsed completely, the wooden upper part often resting on the ground, its integrity essentially preserved, presenting a striking lesson in the relative resistances of the two materials.

Windows.—One of the striking features of the earthquake was the few windows which were broken. In many instances the window frames, without a single pane broken, were seen where the brick walls surrounding them had crumbled and fallen. This immunity seems to indicate that while there was much shaking there was relatively little tortional or crushing movements in the walls. The peculiar feature of window panes perforated by clean-cut round holes,

but not otherwise shattered, were also a striking feature, apparently resulting from bricks or other objects thrown laterally with considerable velocity by the shock.

Curbings and pavings.—In general there was no disturbance of the curbings or pavements in the city. While possibly some occur, none was seen in the dozen or more streets examined by the writer, except a small crack across the pavements at the Victoria Market, said to be due to the shock.

FIG. 10.—General view of ruins in fire district, Kingston, showing absence of disturbance in curbing. (Photo by Fuller.)

Reservoirs and water mains.—The reservoirs and water mains were somewhat disturbed, but not greatly so. The reservoir near Constant Springs was somewhat cracked, and the aqueduct at Hope Culvert broken and a part of the water supply cut off. The mains were rarely appreciably damaged.[1]

Railroad tracks and fixtures.—The steam-railway tracks were

[1] The failure to get water during the fire was due largely to the burial of the hydrants by débris and injury to the engines by falling walls.

practically unaffected, and trains could be run with little difficulty almost immediately after the shock. On the Atlas Wharf, however, the tracks were warped slightly and had to be relaid. In the city a few trolley poles appear to have been titled by the shock, although the greater part were bent by falling débris. In the country few trolley or telegraph poles were affected, generally remaining upright even where near the sea. The sway of the poles seems to have been considerable, nevertheless, many of the wires being snapped, especially in the district east of the city.

Rockfort District

Rockfort is the name applied to the old fort at the government quarries on the coast some three miles east of Kingston. A number of artificial structures were disturbed in this region, principally between the fort and the small stream entering the harbor beyond the old Naval Pier half a mile west of the quarry. At the mouth of the stream mentioned the cement culvert was much damaged, a part being buckled up and faulted (Fig. 11) while other parts were precipitated into the stream. At the same point the gutter was faulted downward several inches along the edge of the sidewalk. It is interesting to note in Fig. 11 that the wooden house, although near the region of greatest disturbance, is little affected.

Along the water front near here the sewer, a large iron pipe, was broken by the shocks, presumably by a buckling in the deposits.

Port Royal

Owing to the failure to get a permit to visit the fort the observations were mainly made from the water. The wooden tower at the southwest terminus is tilted 4 or 5 degrees from the perpendicular. One of the wharves on the harbor side appears to have been tilted toward the land at a considerable angle, the outer end being several feet higher than the inner. A railroad track was arched for a distance of twenty-five yards, the center being four feet above the ends. The sea wall was disturbed and tilted. Many buildings were severely wrenched and partially wrecked, the fact that the damage was not greater being due to the fact that they were of the frame type. One building was noted broken in two where the middle had sagged owing to a depression formed beneath it while the two ends remained elevated.

ATTENDANT FEATURES OF THE EARTHQUAKE

Tidal wave.—Kingston has an inclosed harbor one to two miles in width and five or six miles long, protected from the open sea, except at its mouth at the western end, by the long sand-spit or Palisadoes upon which Port Royal is located. Even the entrance is partially protected by reefs rising nearly or quite to sea level. It is to this fact that Kingston owed its immunity from tidal waves, except those generated within its harbor. These were relatively small, although large and powerful enough to throw one vessel up into the

FIG. 11.—Sidewalk arched and faulted by lateral movement of the walls of a culvert toward the stream. Also illustrates the slight damage to wooden structures. (Photo by F. G. Clapp.)

mud alongside the dock, while another, the Royal Mail Steamer "Arno," barely escaped wrecking by being thrown against the wharf.

Considerable waves were reported at sea, and one sufficient to move small buildings situated near the beach came ashore at Port Antonio on the northeast side of the island. Judging from the fact that the damage is no greater than it is at Port Royal, it is evident that the waves reaching shore at this point were of no great size. A large wave would have washed over the entire point, sweeping everything before it.

PROBABILITY OF FUTURE EARTHQUAKES

The earthquake of 1692 was much more destructive than the one of the present year. It was followed by a long period of relative quiescence, but with sufficient minor shocks to show that the readjustment was not complete until another great slip resulted in the shock of Jamaica, which, together with the subsequent tremblings, show the same is still true of the present time. A temporary local readjustment has, however, probably been reached, but although another severe earthquake may not occur in the near future, destructive shocks will almost certainly occur at some time in the future.

CAUSE

The writer believes the earthquake of January 14 to be due to a displacement along an east-west fracture probably not over three miles in depth at a point three or four miles south of the city, the greatest movement being at a point about four to five miles southeast of the city of Kingston. The disturbance is regarded as probably resulting either from isostatic readjustments or to fracture under the accumulated stresses due to processes of folding or uplift. The reasons are as follows:

1. The direction of movement along the south coast in the vicinity of Kingston varied from southeast-northwest to southwest-northeast, apparently indicating a long line of disturbance rather than a localized center, the position of the fracture being to the south and hence beneath the sea. Movement along such a fault explains the variation of direction of propagation of the vibrations near Kingston, and the tortional movement so characteristic of the later vibrations.

2. The area of greatest disturbance extended from the eastern part of Kingston to Bull Bay, some miles beyond the base of the Palisadoes, as shown by the more severe action on buildings, the greater frequency of fissures, the more profound disturbances in the rocks (as evidenced by the breaking out of springs), by the more frequent prevalence of faulting, fissures, craterlets, and warping in the Palisadoes, and especially by the profound disturbances of the sea bottom leading to the breaking of the cable at a point three and one-half miles southeast of the mouth of Hope River and the base of the Palisadoes.

3. The sharpness and intensity of the vibrations seem to be such as would characterize shocks arising from rock fractures rather than from disturbances due to the slipping of unconsolidated deposits on the inclined sea bottom as suggested by Dr. J. W. Spencer.[1] The shock was distinctly felt by the seismographs at the Weather Bureau at Washington, D. C., the amplitude of movement being about one-fiftieth of an inch, which it is believed would hardly have been the case if due to a landslide in superficial deposits.

4. The elevation of the east end of Jamaica, near which the faulting occurred, is about 7,400 feet, while the sea to the south is approximately 18,000 feet, making a total difference in level of over 25,000 feet. It can easily be conceived that isostatic readjustments, such as would tend to take place wherever such differences of level exist, at closely adjacent points, might have given rise to the fracture. It may be noted in this connection that each of the heavy earthquakes occurring in the western hemisphere in the last year—San Francisco, Valparaiso, Jamaica, and Mexico—all took place in regions of similar sharp differences in elevation. On the other hand, all are in regions characterized by more or less recent distortion, as brought out by the elevated beaches, warped and faulted beds, etc., and folding must be regarded as a possible source of the stresses giving rise to the fractures.

[1] J. W. Spencer, *Science*, N. S., Vol. 25, 1907, pp. 966, 967.

GLACIAL EROSION IN LONGITUDINAL VALLEYS

FRANK CARNEY
Denison University

The recent papers of Professor Sardeson[1] and Mr. Campbell[2] on folds in surface strata, the former within and the latter without the glaciated region, suggest the publishing of some analogous observations made in Owasco Lake (New York) valley.

Two questions will be considered in this paper: (1) Did overriding ice produce the folds, and, (2) if so, what bearing does this disturbance of subjacent strata have in the question of glacial erosion? The localities concerned are shown in Fig. 1, which is a transfer of a portion of the Moravia Quadrangle, omitting the 20-foot contour intervals. Owasco Lake lacks one-fourth of a mile of reaching the northern margin of this sheet. Its former higher levels extended several miles southward, as described in the papers of Watson[3] and Fairchild,[4] these higher levels being marked by numerous deltas. Southward from Locke the valley branches about a salient which reaches an altitude of 1,500 feet. The inlet stream rises some thirteen miles south of the present lake in an outwash plain near Freeville. The rock topography suggests a former divide between Locke and Groton.

DESCRIPTION OF THE FOLDS

The overturned fold shown in Fig. 2 is located on the map, Fig. 1, by station 2, northeast of Locke. The cross-section of the fold is nearly perpendicular and is oriented S. 30° E.; its axis has a tilt of approximately 51°. The disturbed layers are fourteen inches thick, consisting of thin, sandy shale, very much disintegrated. These layers overlie a sandstone bed six inches thick, below which are heavier layers used for building-stone. The disturbed strata are

[1] *Journal of Geology*, Vol. XIV (1906), pp. 226–32.

[2] *Ibid.*, Vol. XIV (1906), pp. 718–21.

[3] *N. Y. State Museum, 51st Ann. Rep.*, Vol. I (1897), pp. 792–94.

[4] *Bull. Geol. Soc. Am.*, Vol. X (1899), pp. 49, 50.

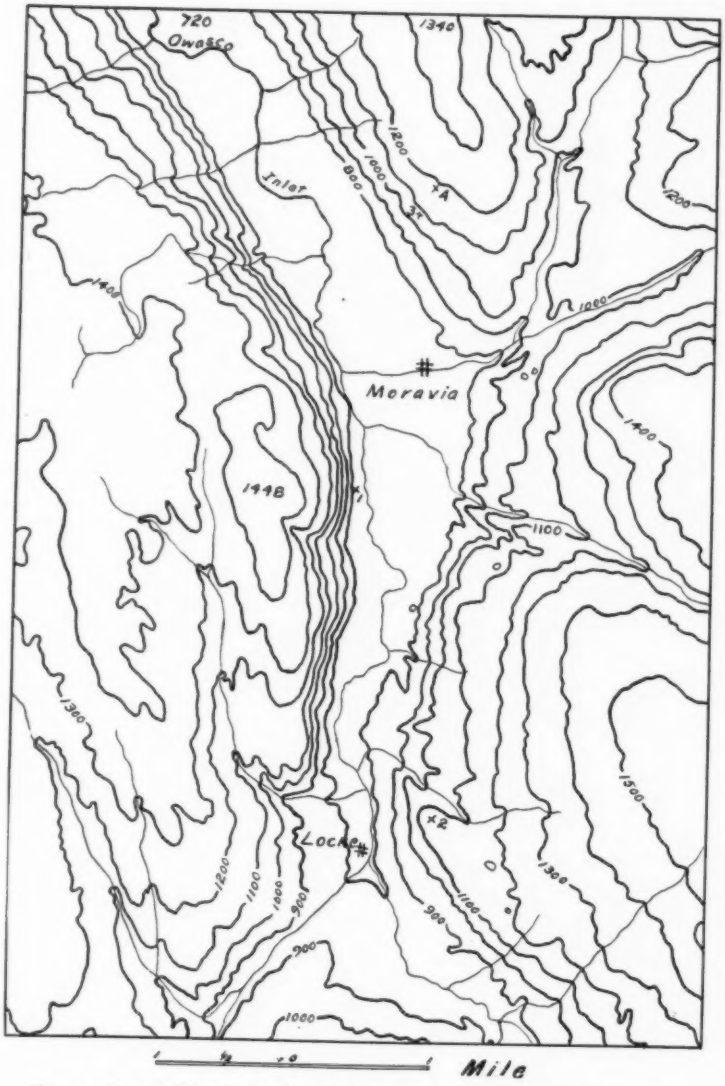

FIG. 1.—Part of Moravia Quadrangle, New York. Contour interval, 100 feet.

overlain by about two feet of drift and rubble, but this horizon very likely consisted formerly of ground moraine which was removed in the process of quarrying.

Fig. 3 is of a fold at station 3, directly north of Moravia. This photograph was taken a few days after an unusually heavy storm which caused many slight streams to leave their former courses, thus exposing fresh sections in the tile. The area shown is on the north side of such a recent cut. The axis of the fold inclines 36°, the section being approximately east-west. The fold is turned up the slope or against gravity; it consists of thin bedded shale and sandy layers amounting to about 18 inches. This is overlain by three to four feet of ground moraine, very compact, and is underlain by a hard layer of sandstone over which the stream is flowing.

HOW THESE FOLDS WERE PRODUCED

As to the causes that may have produced these folds shown in Figs. 2 and 3, which have been selected from a series of photographs of which these are typical: Does the frost theory explain this work? The probable type of a fold caused by freezing is more symmetrical, and, as shown by Sardeson, has in its upper horizon a weathered zone in which the rock has more thoroughly disintegrated, the section blending into less residual material. Fig. 3, however, is obviously below the normal frost line for this climate; while Fig. 2 doubtless shows an area that is subject to frost, as the upper part of the apex of the fold in Fig. 2 very likely has been slightly altered through the influence of frost work. In any event, however, frost folds would be more symmetrical than these. Consequently the frost theory does not seem to apply.

Little need be said concerning the theory of creep, since Fig. 3 is obviously a fold tilted against gravity, while Fig. 2 is a fold along the contour of the slope. It does not seem probable in any event that a fold due to creep would ever be overturned as Fig. 2 is.

Elsewhere in the Moravia Quadrangle folds possibly due to buckling induced by the removal of overlying strata have been observed, but these cases are always symmetrical in relation to the axis of the fold, and apparently show the effects of rather speedy giving away to certain stresses. The agent probably involved in the

removal of the overlying formations is ice, but on this heading too little field work has been done to warrant any definite conclusions. As to the folds in question, it is obvious that they are not due to buckling.

Mr. Campbell establishes the competency of joint expansion due to weathering to produce folds in certain strata. His figures and

FIG. 2.—Subjacent strata folded by glacier ice. Area shown is northeast of Locke, N. Y.

explanation impress the symmetry of such folds. For this reason the theory of weathering cannot apply to our cases.

There are several reasons that point to glacial ice as the agent involved in the present folding. In Fig. 2 the fold is overturned in the direction of ice-motion. This fold lies slightly off the line of the valley segment north of Moravia. Striae to the north and east of the fold, within a radius of one and one-half miles, give an average direction of S. 31° E.,[1] the extremes being S. 18°, and 48° E. Owing

[1] Only magnetic readings are given in this paper.

to the fact that but one section of this fold is exposed there is a possibility of some error in stating exactly the direction of the fold, but from careful study on the ground it seemed plausible that the plain shown in the view is parallel to the direction of ice-motion. If this fold were due to deep-seated stresses, the underlying formations would have suffered disturbance obviously, and since the fold is an over-

FIG. 3.—Subjacent strata folded by glacier ice. Area shown is north of Moravia, N. Y.

turned anticline it seems impossible that any cause of this nature could have become operative without deforming the sandstone beneath.

It is seen that Fig. 3 likewise shows the influence of ice-movements, but not the same type of ice-motion involved in the former case. The topographic map shows a considerable width of valley north of Moravia, a valley which flares northward opening on a fairly level plain within twelve miles. This position favored the expansion toward Moravia of a lobe of ice which had both linear and outward motions. The lateral flow of this tongue obviously produced the fold in question. Some six or seven other instances of similar folds were

noted along the slope within a mile and a half north of Moravia. Some of these were less distorted than the one shown in Fig. 3, one being fairly symmetrical, and possibly to be explained by buckling, since it is several feet below the reach of frost work. But in each case where the axis of the fold was inclined the inclination was up the slope.

It is felt, therefore, that we are dealing with the work of ice in deforming subjacent strata; we have selected cases to illustrate the work of this ice along two lines, one connected probably with the general movement of the ice sheet, or at least the linear movement of a strong valley lobe, the other connected with the outward spreading of a valley lobe.

GLACIAL EROSION

In reference to the altitudes of the localities where folding has been noted: The disturbed strata of station 2 lie approximately 1,140 feet above sea-level. The area of disturbed strata north of Moravia lies within 1,080 and 1,160 feet altitude. Very diligent search at lower and higher ranges than these has not revealed any similar phenomena, but has, however, given much information on the subject of ice-erosion.

Fig. 4 is a photograph of a freshly uncovered rock surface about a mile and a half southwest of Moravia near the foot of the steep valley wall. The well-rounded angles, showing the polishing work of the ice as block after block of the thin bedded sandstone material has been removed, the general smoothing of the whole surface, the irregular gouges and the striae attest the vigor of ice-work here. Several similar areas were likewise noted; the one shown, however, is typical and different from the others only in revealing a larger surface. Here the average direction of the striae is S. 13° E., a direction that shows the control exercised by the valley. This surface has an altitude of about 790 feet, standing but slightly more than 50 feet above the inlet stream near the base of the valley wall. The slope of the polished surface has the general grade of the valley wall immediately above and below. While this surface is very illustrative of the corrasive work of ice, it is felt nevertheless that the processes of ice degradation which it represents are of the same type as have probably been effective in giving the valley cross-section its U-outline.

Directly west of Moravia at approximately the 900-foot contour is another area showing numerous striations which have an average direction of S. 37° E. The surface at this place is slightly steeper than that just noted. It also stands higher above the flood plain below.

East of Moravia near the forks in the highway leading up the hill is another area of very active ice-polishing. Its altitude is 830 to

FIG. 4.—Glaciated surface southwest of Moravia, N. Y.

860 feet. We note here, however, two sets of striae; the stronger measures S. 56°–63° E. This set probably represents the general movement of the ice-sheet, modified perhaps slightly by local topography. The direction of the weaker set is S. 19°–25° E. It should be noted that this surface stands at an angle in the Owasco Inlet valley. The north leg of this angle has approximately the direction of N. 32° W., and the south leg, S. 8° W. Leading into the major valley from the east a tributary valley enters at this point. The striated surface, however, is some 100 feet below the rock bottom of this tributary valley which in accordance with the recent literature would be called a "hanging valley." It is possible, therefore, that

this relation of valleys here has tended to mollify the general effectiveness of ice-corrasion.

On the uplands striated surfaces again appear. These surfaces range from 1,200 to 1,400 feet in altitude, and even above this they are to be found on the salients opposed to the direction of ice-motion. Averages of several scores of readings made in different localities ranging between the 1,200- and 1,400-foot contours give S. 46°–48° E. The averages of striae on surfaces still higher give S. 53°–61° E. These areas fall within a reach of three miles of the major

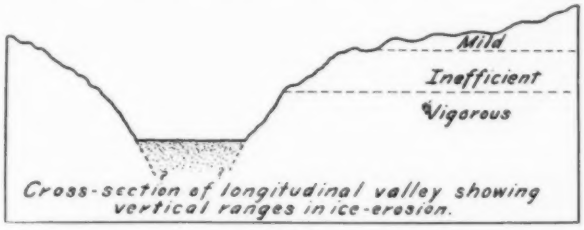

FIG. 5.—Cross-section of longitudinal valley showing vertical ranges in ice-erosion.

valley; in the main they are found in the general flat country constituting plateau divides.

Between the two zones of ice-erosion already mentioned, that is the areas near the bottom of the major valley and the areas on the uplands, lies another zone of least effective ice-work. This is the horizon of the folded subjacent strata; in the Owasco valley area it is approximately between the 1000- and 1200-foot contours.

Fig. 5 summarizes these observations. The cross-section is normal to the axis of the longitudinal valley, not taking note of the deflections of this axis. The matter of altitude in relation to sea-level is likewise neglected, as great discordance may exist between present-day and Wisconsin ice-epoch altitudes. So little is known definitely about the relation that existed, during Pleistocene time, between the land mass of northeastern North America and sea-level, and furthermore, the connection between ice-erosion and a base level from which altitude is measured, may probably be so slight, that this relation, as a factor, may safely be neglected. The topographic

aspect of the region of our cross section, however, is very important. In the uplands, or divide plateau areas, glaciated surfaces are found wherever the rock is not drift-covered. These striated surfaces attest considerable planing or abrasive work by the ice-sheet. As these flat elevated areas decline to the valleys we find a range of very subdued ice-work, the zone of disturbed subjacent strata, and of residual rock decay *in situ*. But proceeding down the valley slopes the evidence of ice-corrasion gradually increases. The strongest evidence so far noted in the field is found within a short distance vertically of the flood plain. We have then (Fig. 5) three ranges showing variation in the effectiveness of ice-erosion: (1) the range of mild erosion; (2) of inefficient erosion; and (3) of vigorous erosion.

Reviews

A Note on the Geology of Gough Island. By J. H. Harvey Pirie. *Notes on the Petrology of Gough Island.* By R. Campbell. (Proceedings of the Royal Physical Society of Edinburgh, session 1905–06; Vol. XVI, No. 6, pp. 258–66. Edinburgh, 1907.)

This island is a peak in lat. 40° 20′ S., long. 9° 56′ W. composed of horizontal basalts, trachytes, trachy-dolerites, and tuffs. The island is encircled by wave-cut cliffs over which the streams cascade into the sea.

C. W. W.

Montana Coal and Lignite Deposits. By Jesse Perry Rowe. (Bulletin No. 37, University of Montana, Geological Series No. 2. Pp. 82, 26 plates. Missoula, Mont., 1906.)

Coal occurs in the Jurassic, Cretaceous, and Tertiary. The workable coal is limited to the Cretaceous and is both lignitic and bituminous. Mining is carried on to supply the local demand only, most of the coal being used in connection with smelting and other industries. In 1904 the state produced about 1,500,000 tons of coal and lignite, valued at about $2,450,000. The annual output of coke is about 57,000 tons.

C. W. W.

Geological Survey of Michigan, Annual Report, 1904. Including a geological map of Michigan. Pp. 182, 16 plates. Lansing, Mich., 1905.

Contents: "Failure of Wells along the Lower Huron River, Michigan, in 1904," by Myron L. Fuller; "A Geological Reconnaissance along the North Shores of Lake Huron and Michigan," by Israel C. Russell; "Sixth Annual Report of the State Geologist," by Alfred C. Lane.

C. W. W.

Iowa Geological Survey (Vol. XV, Annual Report, 1904). By Frank A. Wilder, State Geologist, Des Moines, 1905.

Contains: "Statistics of Mineral Production for 1904;" "Cement and Cement Materials of Iowa," by Edwin C. Eckel and H. F. Bain; and reports on the geology of seven counties. C. W. W.

Maryland Geological Survey, Vol. V, 1905. By WILLIAM BULLOCH CLARK, State Geologist. Baltimore, 1905.

Contains reports on magnetic observations, county boundaries, highways, coals, coal formations and their correlation, coal mines, and on the chemical and heat-producing properties of Maryland coals.

The Configuration of the Rock Floor of Greater New York. By WILLIAM HERBERT HOBBS. (Bulletin No. 270, U. S. Geological Survey. Pp. 96, 5 plates. Washington, D. C., 1905.)

This paper is a record of existing data on the form of the rock surface of New York. The waterways about Manhattan Island are described as steep rock canyons 200 to 300 feet deep, partially filled with drift. The main lineament of the rock topography is assigned to faulting.

C. W. W.

Tertiary and Quarternary Pectens of California. By RALPH ARNOLD. (U. S. Geological Survey, Professional Paper No. 47. Pp. 264, 53 plates. Washington, D. C., 1906.)

This paper is a monograph of the California fossil Pectens, and contains also descriptions of Pectens from other localities on the Pacific Coast, with a summary of California Marine Tertiary paleontology.

C. W. W.

Cretaceous Section in the Moose Mountains District, Southern Alberta. By D. B. DOWLING. (Bulletin of the Geological Society of America, Vol. XVII, pp. 295–302. 1906.)

The formations described are: the Kootanie, Dakota, Colorado, Eagle, Claggett, Judith River (Belly River), Bearpaw (Pierre), and Edmonton (Saint Mary River). A fuller report will be made by Mr. D. D. Cairnes.

C. W. W.

Status of the Mesozoic Floras of the United States. By LESTER F. WARD, with the collaboration of WILLIAM M. FONTAINE, ARTHUR BIBBINS, and G. R. WIELAND. Second Paper. (U. S. Geological Survey, Monographs, Vol. XLVIII. Part I, text, 616 pp.; Part II, 119 plates. Washington, D. C., 1905.)

This report contains descriptions of the Triassic flora of Arizona; the Jurassic floras of Oregon, Alaska, California, Montana and Wyoming;

and the Cretaceous floras of the Potomac and Shastan Series, and of the Kootanie (Montana), Lakota (Black Hills), and Trinity (Texas) formations. C. W. W.

Geological Survey of Ohio. By EDWARD ORTON, JR., State Geologist, Bulletin Nos. 4 and 5, Fourth Series. Columbus, Ohio, 1906.

Contains: "The Limestone Resources and the Lime Industry in Ohio," by E. Orton, Jr., and S. V. Peppel, and "The Manufacture of Artificial Sandstone or Sandlime Brick," By S. V. Peppel.

The Differentiation of a Secondary Magma through Gravitative Adjustment. By REGINALD A. DALY. Separate from the *Festschrift zum siebzigsten Geburtstage von Harry Rosenbusch, gewidm. v. seien Schülern.* Stuttgart: E. Schweizerbartsche Verlagsbuchhandlung, 1906. Pp. 201–32.

This paper is similar to an earlier one[1] by the same author, but contains a fuller description and new chemical analyses of the Moyie Sell in the Purcell Range of British Columbia. This great sill, 840 meters thick, is composed of hornblende gabbro grading upward into granitite which lies along the upper surface with a thickness of about 45 meters. The latter rock is thought to have been derived by assimilation of the country rock (quartzite) in the gabbro, and subsequent segregation of the lighter granitic material at the top of the sill. C. W. W.

The Champlain Deposits of Northern Vermont. By C. H. HITCHCOCK. (From the *Fifth Report on the Geology of Vermont*, by PROFESSOR G. H. PERKINS.) Pp. 24. Montpelier, Vt., 1906.

According to the author it is easier to invoke the glacial dam to account for the various Pleistocene beaches, benches, wave-cut notches, and sea cliffs than to appeal to changes of level. Glacial Lake Champlain may have been from 200 to 300 feet higher than the marine limit. Glacial Lake Memphremagog discharged through the Elligo pond col into the Lamoille Valley and was tributary to Glacial Lake Champlain.

C. W. W.

New Forms of Concretions. By HENRY WINDSOR NICHOLS. Publication 111, Geological Series, Field Columbian Museum, Vol. III, No. 3. Pp. 25–54; plates IX–XXVII. Chicago, 1906.

[1] "The Secondary Origin of Certain Granites," *American Journal of Science*, Vol. XX, pp. 185–216. 1905.

Very complete descriptions are given of new types of concretions from many localities. Students of concretions will find in this paper some original and helpful methods of research. There are also observations which may bear on the principles of ore-deposition. Some concretions from the deep-sea are found to have the composition of dolomitic limestone, indicating that dolomite may be formed directly from ocean water. The paper closes with a useful discussion of the determination of the specific gravity and the modulus of rotundity of concretions.

C. W. W.

The Geology of the Granby Area. By E. R. BUCKLEY AND H. A. BUEHLER. Missouri Bureau of Geology and Mines, Vol. IV, Second Series. Jefferson City, Mo., 1906.

The authors conclude that faults have had nothing to do with the origin of the lead and zinc ores of this district. The so-called fault breccias are mostly basal conglomerates of the Pennsylvanian System. Nor were the ores derived from the underlying Cambro-Ordovician magnesian limestone by an artesian circulation, as held by Van Hise, Bain, and others, because the water from deep wells in the latter rock contains no zinc or lead. The ores were probably derived from overlying Pennsylvanian shales and limestones, and concentrated wholly by downward-moving waters.

The report contains an extended discussion of the chemistry of the ores and a few pages on methods of mining, concentrating, and melting.

C. W. W.

Geological Survey of New Jersey. Annual Report of the State Geologist for the year 1905. By HENRY B. KÜMMEL, State Geologist. Trenton, N. J., 1906.

The report contains: "Changes along the New Jersey Coast," by Lewis M. Haupt; "A Brief Sketch of Fossil Plants," and "The Flora of the Cliffwood Clays," by Edward W. Berry; "The Chemical Composition of the White Crystalline Limestones of Sussex and Warren Counties," by Henry B. Kümmel, with analyses by R. B. Gage; "Lake Passaic Considered as a Storage Reservoir," by C. C. Vermeule; "A Report on the Peat Deposits of Northern New Jersey," by W. E. McCourt and C. W. Parmelee; "The Mining Industry," by Henry B. Kümmel.